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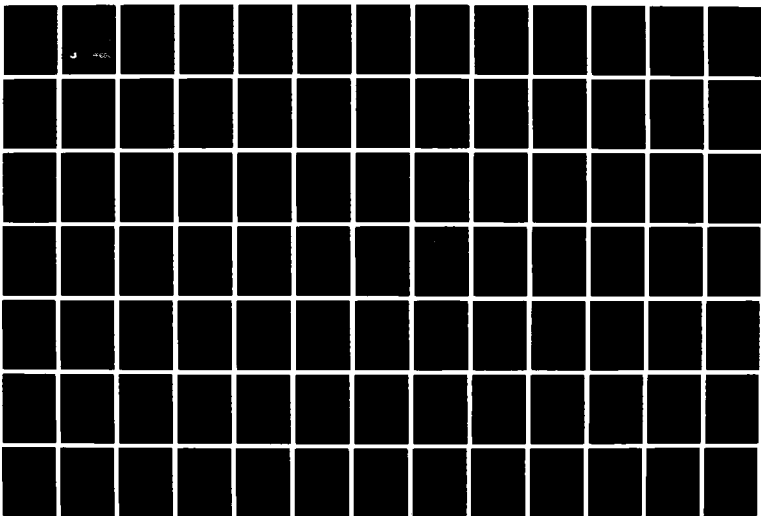
VOLATILE ORGANIC COMPOUND AND PARTICULATE EMISSION
STUDIES OF AF (AIR FOR. (U) ACUREX CORP MOUNTAIN VIEW
CA ENVIRONMENTAL SYSTEMS DIV J AYER ET AL. JUL 88
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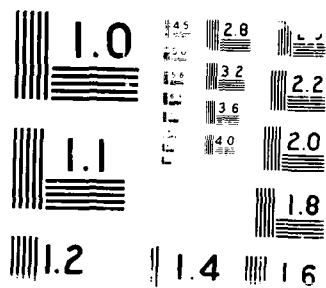
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VOLATILE ORGANIC COMPOUND AND PARTICULATE EMISSION STUDIES OF AF PAINT BOOTH FACILITIES: PHASE I

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JULY 1988

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) The results of volatile organic compound (VOC) and particulate emission studies at three Air Force spray paint facilities are presented. It was found that all three facilities (one at McCellan AFB CA and two at Travis AFB CA) were out of compliance for VOC emissions. The possibility of reducing VOC emissions with recirculation modifications and various control strategies is discussed. Specific recommendations for emission reductions pertaining to each of the facilities are presented.					
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SUMMARY

A. OBJECTIVE

This study presents the results of volatile organic compound (VOC) and particulate emission surveys performed at three Air Force painting facilities. The three facilities -- one in McClellan AFB building 655 and two at Travis AFB in buildings 550 and 1014 -- did not meet local VOC emission standards. This report discusses the possibility of reducing these emissions with recirculation modifications and various VOC reduction and control strategies.

Although VOC emissions from paint spray booths can be controlled by add-on control systems, control is expensive for present air flow rates. The use of air recirculation within the spray booth can reduce the cost of VOC emission controls by reducing the quantity of air which requires processing. Recirculation systems were designed for two of the painting facilities included in this study. In designing the systems, various criteria such as paint booth VOC concentrations and health and safety standards were considered. Add-on VOC emission control systems which can be used in conjunction with the recirculation system are evaluated in this study. The devices of interest are a solvent incineration system and an activated carbon adsorption bed. The VOC removal efficiency, initial capital investment and operating costs for both of these technologies are discussed.

B. BACKGROUND

The Air Force uses a number of solvents and solvent-based coatings in many routine operations that are required to maintain aircraft-related equipment. Specific activities which result in the emission of large quantities of VOCs include metal cleaning, painting, paint removal, fuel storage and transfer, and industrial waste treatment. As a result of these operations, significant quantities of VOCs are released into the atmosphere. For this reason, Air Force operations comprise one of the VOC source categories regulated by the Clean Air Act and state and local laws.

Solvent-based epoxy primers and solvent-based polyurethane topcoats are normally used by the Air Force for painting aircraft. Methyleneethyl ketone, isopropyl alcohol, toluene, lacquer thinner, and aliphatic polyurethane thinner are the solvents generally involved in painting. Currently the solvents, primers, coatings for corrosion control and aerospace topcoats used by the Air Force exceed VOC emission limits established by both federal and state laws. The statutory deadline to comply with both state and federal laws is December 31, 1987.

The study of VOC and particulate emissions and possible reduction strategies at the three Air Force painting facilities took place between June and September, 1987. Painting operations at McClellan AFB in Building 655 were observed between June 1 and June 5. Painting operations at Travis AFB

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C. PROJECT DESCRIPTION

The project was conducted in two steps. Step 1 involved characterizing the VOC and particulate emissions from the painting facilities included in this study. Step 2 was to make recommendations, based on the data collected in Step 1, of viable VOC emission reduction and control options for each of the facilities.

Step 1 was accomplished by observing the paint operations occurring at each of the facilities, and sampling for organics and particulates both inside and outside the paint booth. The sampling methods used to characterize the emissions were National Institute of Safety and Health (NIOSH) 500, NIOSH 1300, Modified Method 5, anemometer volume flow, EPA Method 2 volume flow, ST-7 and Method 25A. In addition, records of paint usage rates and paint booth operations were kept. At McClellan AFB, water samples were drawn from the water curtain sumps which remove particulate from the exhaust flow.

Step 2 was accomplished by analyzing the data and developing possible VOC emission control strategies for each of the painting facilities included in this study.

D. CONCLUSIONS AND RECOMMENDATIONS

- All three painting facilities included in this study failed to meet applicable VOC emission standards.
- The adoption of more efficient paint application methods is a viable VOC emission reduction strategy.
- Paint booth recirculation modifications associated with an add-on control device would result in significant VOC emission reductions.
- A recirculation system could be installed at the McClellan AFB Building 655 paint facility at an approximate cost of \$47,000. The bleed-off volume required to maintain the VOC concentration below established safety limits is 1,500 scfm.
- A recirculation system could be installed at the Travis AFB Building 1014 painting facility at an approximate cost of \$33,000. The bleed-off volume required to maintain the VOC concentration below established safety limits is 860 scfm.
- Recommendations specific to each site regarding safe and efficient paint booth operation were also made.
- A recirculation system could be installed at the Travis AFB Building 1014 painting facility at an approximate cost of \$33,000. The bleed-off volume required to maintain the VOC concentration below established safety limits is 860 scfm.
- Recommendations specific to each site regarding safe and efficient paint booth operation were also made.


PREFACE

This report was prepared by the Acurex Corporation, Mountain View, California, under Environmental Protection Agency (EPA) Contract No. 68-02-3973, Task No. 8. The EPA was funded by Air Force Engineering and Services Center, Air Force Engineering and Services Laboratory (AFESC/RDVS), Tyndall Air Force Base, Florida 32403-6001, to conduct this study for the Air Force.


This report summarized the work done by Acurex Corporation between February 1987 and December 1987. It was performed under the direction of Dr Dean Wolbach, Acurex Corp. The US EPA Work Assignment Officer was Charles H. Darwin, Air and Energy Engineering Research Laboratory, Research Triangle Park, North Carolina. Mr Surendra B. Joshi, AFESC/RDVS, was the Air Force project officer for this contract.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for public release.


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SECTION I

INTRODUCTION

A. BACKGROUND

The Air Force uses a number of organic coatings and solvents in maintaining aircraft and aircraft-related equipment. Activities such as metal cleaning, painting, paint removal, fuel storage and transfer, and industrial waste treatment produce large quantities of VOCs which are released into the atmosphere. For this reason, Air Force operations comprise one of the VOC source categories regulated by the Clean Air Act and state and local laws designed to reduce emissions of organic ozone precursors. Because many areas have not yet attained ozone control goals set by the Clean Air Act, local agencies are applying increased pressure on Air Force facilities to decrease VOC emissions.

This study focused on Air Force painting operations. Solvent-based epoxy primers and solvent-based polyurethane topcoats are normally used by the Air Force for painting aircraft. Methyl ethyl ketone (MEK), isopropyl alcohol, toluene, laquer thinner and aliphatic polyurethane thinner are the solvents generally involved in painting. The solvents, primers, coatings for corrosion control, and aerospace topcoats used by the Air Force exceed VOC limits established by both federal and state laws. The statutory deadline to comply with both the state and federal laws is December 31, 1987.

B. OBJECTIVE

The objective of this effort was to identify appropriate control technologies which would minimize emission of VOCs and other hazardous air pollutants (HAPs) from facilities where routine painting operations take place at typical Air Force Bases. Of particular interest are paint spray booths which are sources of large, uncontrolled VOC emissions.

C. SCOPE/APPROACH

The project was divided into two phases. Phase I consisted of the characterization of VOC and HAP emissions from typical Air Force painting facilities and the identification of appropriate VOC emission control technologies for these facilities. Three painting facilities at two Air Force bases were studied to gather emissions characterization data such as temperatures, pressures, flowrates, and emissions concentrations. Knowledge of these variables is required to identify control options. The procedures used to characterize these variables are presented in Appendix C. Phase I addresses issues and makes recommendations regarding the pilot-scale testing of appropriate control technologies for the reduction of VOC and HAP emissions.

Phase II of this project is the implementation recommendations made in Phase I.

SECTION II

PAINT BOOTH EMISSIONS CHARACTERIZATION

A. McCLELLAN AIR FORCE BASE

The McClellan Air Force Base downdraft water curtain paint spray booth is located inside Building 655. The unit is approximately 60 feet long, 18 feet wide, and 18 feet tall. Air is ducted through a particulate filter system on the roof of the main building and routed through the ceiling of the spray booth. The air flows downward, through floor gratings, and passes through a water curtain. Each sump is serviced by two ducts equipped with radial fans which exhaust to roof vents. The paint booth is maintained under negative pressure and is, therefore, subject to in-leakage. A schematic of the paint booth and the associated sampling locations used to characterize the VOC concentration profile is given in Figure 1. In addition, the sampling locations are listed in Table 1.

1. Paint Processes and Usage

Before sampling, a list of paints to be used for the duration of the test was compiled. Samples of these paints were analyzed for residue and VOC content, and the results were used to aid in organic speciation analyses of the VOC samples drawn from the air and the water. Table 2 lists the primary components of the paints used during the test, and Table 3 gives the results of the paint residue analysis.

Because of the large number of exhaust vents, it was anticipated that the particulate and organic concentrations in both the water and the air samples would depend on where in the booth the paint was applied, as well as the orientation of the surface painted. For this reason, the facility was divided into quadrants associated with the four water sumps. Records were kept of where, in terms of these quadrants, the paint was applied, as well as the time and rate at which the paint was consumed. These records are summarized in Tables 4 and 5. The particulate and organic sampling results are correlated with these records in subsequent sections.

2. Flow Measurements

Two flow measurement procedures were used to determine volume flow through the paint spray booth:

- Daily anemometer readings were taken at the floor grates.
- Pitot tube readings were taken in each exhaust duct according to EPA Method 2.

These procedures are discussed more fully in Appendix C.

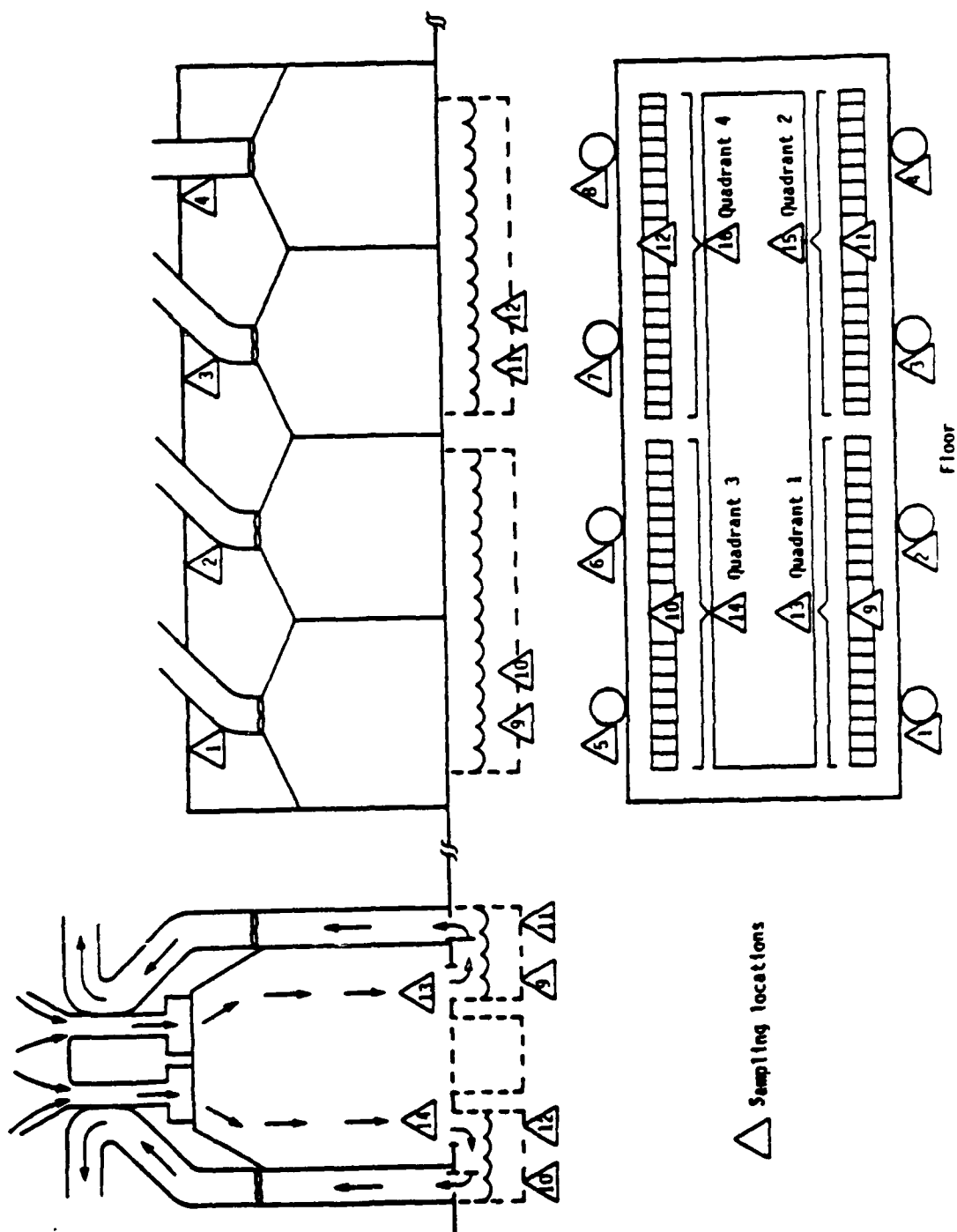


Figure 1. Schematic of Paint Spray Booth -- McClellan Air Force Base.

TABLE 1. LIST OF SAMPLING LOCATIONS --
McCLELLAN AIR FORCE BASE

Location number	Description
1	Exhaust vent duct 1 (Quadrant 3A)
2	Exhaust vent duct 2 (Quadrant 3B)
3	Exhaust vent duct 3 (Quadrant 4A)
4	Exhaust vent duct 4 (Quadrant 4B)
5	Exhaust vent duct 5 (Quadrant 1A)
6	Exhaust vent duct 6 (Quadrant 1B)
7	Exhaust vent duct 7 (Quadrant 2A)
8	Exhaust vent duct 8 (Quadrant 2B)
9	Quadrant 3 sump
10	Quadrant 1 sump
11	Quadrant 4 sump
12	Quadrant 2 sump
13	Quadrant 3 grating
14	Quadrant 1 grating
15	Quadrant 4 grating
16	Quadrant 2 grating

TABLE 2. GC/MS ANALYSES OF PAINT SAMPLES -- McCLELLAN AIR FORCE BASE

Compound (mg/L)	Sample Numbers ^a											
	905345	905349	905351	905347	905357	905355	905499	905353	905361	905363	905364	905358
Chloromethane					500			100		100		
Toluene	2,300	150	150	100	450	50	150	400	93,000		500	
Ethylbenzene	1,050	1,700	1,300	1,650	200	50	1,200	4,450	10,500		350	
Acetone	200	250	300	350	350	200	150	200	200		800	
2-Butanone	5,400						200	50	>210,000	750	2,400	
2-Hexanone	1,000	1,750	1,700	1,550			1,250	39,000				
4-Ethyl-2-pentanone	1,350	1,600	1,800	1,850		300	2,400	>425,000				
Butyl acetate	13,000	17,000	18,000	15,000			20,000	>85,000	>95,000			
5-Methyl-2-hexanone	>120,000 ^b	>180,000	>150,000	>150,000			>160,000					
Total Xylenes	5,000	9,500	6,000	8,000	4,000	150	4,000	10,000	30,000		800	
Propylbenzene				2,000	15,000							
2-Butoxyethanol					>105,000	>65,000				>19,0000	>155,000	
2-Propanol											50	
1,1-Dichloroethane							300		>150,000			
1,1,1-Trichloroethane												
Unknown #467	11,250											
Unknown #286											>115,000	
Unknown #482									7,500			
Unknown #197												9,250

^aThe sample numbers correspond to the following paints:

905499	MIL-C53039 DESERT SAND	905353	MIL-C-22750 WHITE	905361	MIL-T-81772A AIRCRAFT THINNER
905345	MIL-C-53039 SAND	905355	24410 SEAFOAM GREEN	905363	DOD-P-15328 WASH PRIMER
905347	HS-461688	905357	MIL-P-85582 YELLOW	905364	DOD-P-153280 WASH PRIMER
905349	MIL-C-53039 BLACK	905358	MIL-P-85582 YELLOW		(RESIN COMPONENT)
905351	MIL-C-53039 BROWN		(CATALYST COMPONENT)		

^bLower bound values indicate that the concentration of this compound was too high, and therefore saturated the gas chromatograph mass spectrometer.

TABLE 3. RESIDUE ANALYSIS OF PAINT SAMPLES --
McCLELLAN AIR FORCE BASE

Sample	Paint type	Initial weight	Final weight	Percent volatile
905344	Desert Sand	0.5408	0.3151	41.7
905345	Sand	0.6532	0.4128	36.8
905347	Green	0.6038	0.3491	42.2
905349	Black	0.5613	0.334	40.5
905351	Brown	0.7415	0.463	37.6
905353	White	0.4172	0.2288	45.2
905355	Seafoam Green	0.5846	0.1895	67.6
905361	Aircraft Thinner	0.3238	0.00	100
<u>Mixtures</u>				
905357	Aircraft Primer	1.1142	0.5028	54.9
905358	Primer Catalyst			
Water				
3:1:2 ^a				
905363	Wash Primer	0.4416	0.0293	93.4
905364	Primer Catalyst			
Ethanol				
4:1:1 ^b				

^aThe aircraft primer components: aircraft primer, primer catalyst and water were mixed in a ratio of 3:1:2.

^bThe wash primer components: wash primer, primer catalyst and ethanol were mixed in a ratio of 4:1:1.

TABLE 4. PAINT BOOTH OPERATING LOG -- McCLELLAN AIR FORCE BASE

Day	Time	Quadrant	Paint time (min)	Comments
June 2	0923 - 0932	1,2,3,4	:48	2 operators & 1 gun, shelter
	0940 - 0943	1,2,3,4	3:00	2 operators & 1 gun, shelter
	1052 - 1102	1,3	7:25	2 operators & 1 gun, shelter
	1235 - 1303	1,3	17:51	2 operators & 1 gun, shelter
	1347 - 1357	1,3	8:36	2 operators & 1 gun, exterior shelter
June 3	0924 - 0933	1,2,3,4	5:05	4 operators & 1 gun, undercoat 2 shelters
	1020 - 1025	2,4	4:10	2 operators & 1 gun, exterior & interior shelter
	1032 - 1056	1,3	19:34	2 operators & 1 gun, exterior shelter
	1310 - 1324	1,3	23:38	2 operators & 1 gun, exterior shelter
	1251 - 1331	2,4	26:42	2 operators & 1 gun, exterior & interior shelter
	1431 - 1505	1,3	24:18	2 operators & 1 gun, exterior shelter
	1703 - 1725	1,3	17:03	1 operator, exterior shelter
June 4	0805 - 0845	1,3	40:00	Sanding only
	0923 - 0940	1,3	17:00	Sanding only
	0928 - 1110	2,4	46:44	2 operators & 1 gun, exterior shelter
	1044 - 1049	1,3	5:00	2 operators & 1 gun, interior shelter
	1223 - 1238	1,3	9:45	2 operators & 1 gun, interior shelter
	1240 - 1307	2,4	10:25	2 operators & 1 gun, exterior shelter
	1324 - 1335	1,3	10:14	1 operator, interior shelter
	1322 - 1333	2,4	9:12	1 operator, interior shelter
	1425 - 1436	1,3	6:46	2 operators & 1 gun, interior shelter
June 5	0850 - 0900	2,4	10:00	Air blowing shelter
	0947 - 1010	2,4	10:42	1 operator, exterior shelter

TABLE 5. PAINT USAGE LOG -- McCLELLAN AIR FORCE BASE

Day	Time	Quadrant	Paint type used	Amount used (kg)	Comments
June 2	0923 - 0932	1,2,3,4	NI ^a	NI	2 operators & 1 gun, shelter
	0940 - 0943	1,2,3,4	NI	NI	2 operators & 1 gun, shelter
	1052 - 1102	1,3	Wash primer	NI	2 operators & 1 gun, shelter
	1235 - 1303	1,3	Aircraft primer	7.6	2 operators & 1 gun, shelter
	1347 - 1357	1,4	Seafoam green	2.4	2 operators & 1 gun, exterior shelter
June 3	0924 - 0933	1,2,3,4	Undercoating	NI	4 operators & 1 gun, undercoat 2 shelters
	1020 - 1025	2,4	Wash primer	5.3	2 operators & 1 gun, exterior & interior shelter
	1032 - 1056	1,3	Wash primer	0.85	2 operators & 1 gun, exterior shelter
	1310 - 1324	1,3	Epoxy primer	9.3	2 operators & 1 gun, exterior shelter
	1251 - 1331	2,4	Epoxy primer	8.9	2 operators & 1 gun, exterior & interior shelter
	1431 - 1505	1,3	Brown hentzen	4.9	2 operators & 1 gun, exterior shelter
	1703 - 1725	1,3	Brown hentzen	6.3	1 operator, exterior shelter
June 4	0805 - 0845	1,3	Particulate	--	Sanding only
	0923 - 0940	1,3	Particulate	--	Sanding only
	0928 - 1110	2,4	Polyurethane green	14.4	2 operators & 1 gun, exterior shelter
	1044 - 1049	1,3	Resin wash primer:	0.63	2 operators & 1 gun, interior shelter
	1223 - 1238	1,3	Aircraft primer	6.6	2 operators & 1 gun, interior shelter
	1240 - 1307	2,4	Hentzen black	0.1	2 operators & 1 gun, exterior shelter
	1322 - 1333	2,4	Hentzen brown	0.1	1 operator, interior shelter
	1324 - 1335	1,3	Seafoam green	2.6	1 operator, interior shelter
	1425 - 1436	1,3	Seafoam green	1.8	2 operators & 1 gun, interior shelter
June 5	0850 - 0900	2,4	Particulate	--	Air blowing shelter
	0947 - 1010	2,4	Wash primer	2.4	1 operator, exterior shelter

^aNo information is available.

Each of the four floor grates was divided into six sections, and a daily flow measurement was taken with the anemometer over each area. The results of the integrated flow calculations are given in Table 6.

EPA Method 2 volume flow measurement procedures were used to determine air flowrates in the exhaust ducts. This procedure requires the use of a pitot tube in a straight duct at a location 8 duct diameters downstream of any flow obstructions or variations.

The results of the EPA Method 2 volume-flow measurements are given in Table 7. Because the ducts leading from the water curtain to the roof are extremely curved, there are no accessible locations where a straight run of even two diameters can be obtained, thus, it was not possible to comply with the Method 2 protocol. In addition, free-swinging dampers in the ducts further upset the flow. The obstacles and routing in the ducts cause the airflow to be nonlaminar. For this reason, vortical flow and recirculation were often detected with the pitot tube (a negative pressure differential is indicative of vortical flow) (1). If a negative pressure differential was measured, a zero value was substituted. In this way, the volume flow (and therefore, the hydrocarbon and particulate emission levels) were overpredicted, rather than underpredicted.

3. VOC Measurements

Four test series were used to measure the VOC concentrations in both the spray booth and the exhaust ducts:

- The EPA Modified Method (MM5) particulate and organic train was used to measure semivolatile organic compounds in the exhaust ducts.
- The BAAQMD Method ST-7 and as the EPA Method M25A were used in the exhaust ducts to determine total organic carbon emissions.
- The NIOSH 1300 method was used in the spray booth and the exhaust ducts to both quantize and speciate VOC emissions.

These procedures are discussed more fully in Appendix C.

The results of the semivolatile organic module analyses of the MM5 sampling tests are presented in Table 8. The compounds of highest concentrations (such as xylene) were found in the paint samples (see Table 2). During the Test 1 sampling interval in Stack 2 (corresponding to Quadrant 1), 19 minutes of painting took place in Quadrants 1 and 3 while only 4 minutes of painting took place in Quadrants 2 and 4. It was, therefore, anticipated that high concentrations of organics would be detected. It was expected that high VOC concentrations would also be detected during Test 2 because 24 minutes of painting took place in Quadrants 1 and 3. High concentrations were found but the compounds detected were significantly different from the compounds found in Test 1, probably because a different paint was used (see Table 2).

TABLE 6. VOLUMETRIC FLOWRATE ANEMOMETER DATA -- McCLELLAN AIR FORCE BASE

Site	Volume flow (cfm)			
	June 1	June 2	June 3	June 4
Sump 1	14,555	11,366	17,286	13,249
Sump 2	10,922	11,866	12,401	11,315
Sump 3	10,922	9,551	15,026	12,275
Sump 4	<u>14,209</u>	<u>11,450</u>	<u>15,638</u>	<u>15,676</u>
Total	50,608	44,233	60,351	52,515
Temperature (°F)	82.1	82.0	82.0	84.0
Barometric Pressure (in. Hg)	29.75	29.5	29.9	29.7
Total (cfm @ STP)	49,020	42,493	58,763	50,604
Total (Lpm @ STP)	1,387,266	1,202,552	1,662,992	1,432,093

TABLE 7. VOLUMETRIC FLOWRATE EPA METHOD 2 --
McCLELLAN AIR FORCE BASE

Site	Volume flow (cfm @ STP)	
	June 1	June 4
Stack 1	8,523	7,767
Stack 2	6,405	6,903
Stack 3	7,018	7,157
Stack 4	7,477	7,993
Stack 5	3,499	3,863
Stack 6	3,729	4,581
Stack 7	9,247	9,154
Stack 8	<u>6,400</u>	<u>5,852</u>
Total	52,298	53,270
Total (Lpm @ STP)	1,480,033	1,507,541

Percent difference: 1.8

TABLE 8. MM5 ORGANICS SAMPLING RESULTS -- McCLELLAN
AIR FORCE BASE

	Test 1	Test 2
Date	6-3-87	6-3-87
Time	1018-1118	1430-1530
Site	Stack 2	Stack 2
Quadrant		
Volume sampled (cf @ STP)	31.16	35.01
Volume sampled (L @ STP)	883	992
Semivolatile compounds detected ($\mu\text{g}/\text{sample}$)		
Naphthalene	4	5
Acenaphthylene	3	0
Diethyl phthalate	12	4
Di-n-butyl phthalate	7	7
Butylbenzyl phthalate	2	2
bis(2-ethylhexyl)phthalate	150	70
Di-n-octyl phthalate	4	7
Benzoic acid	56	120
Ethylbenzene	95	0
Xylene (1 isomer)	180	0
2,4,6-trimethyl octane	42	0
2,3,4-trimethyl heptane	51	0
3-Methylnonane	35	0
Butylcyclohexane	35	0
Dimethylnonane (3 isomers)	130	20
5-Methylundecane	41	0
Decamethylcyctopenta-siloxane	55	0
Propylbenzene	0	59
Ethyl-methylbenzene (2 isomers)	0	400
Trimethylbenzene (3 isomers)	0	670
Ethenylbenzene	0	24
1-Methyl-2-propylbenzene	0	32
2,5,8,11,14,17-Hexaoxaoctadecane	0	33

Both EPA Method 25A and BAAQMD Method ST-7 are gas analysis procedures which determine the total oxidizable carbon (TOC) concentration in a sample stream. TOC is comprised of the organic carbon and carbon monoxide present in the sample. For the tests discussed in this report, the contribution of carbon monoxide to the TOC concentration was considered negligible (CO concentration in air is generally a few parts per million), thus, the measured TOC was considered to be solely from an organic source.

The BAAQMD ST-7 procedure requires a gas sample to be passed through a combustion tube, where all organic carbon atoms are oxidized to CO_2 (2). From the combustion tube, the sample is passed through a nondispersive infrared analyzer (NDIR) which continuously monitors the CO_2 concentration in the gas stream. Periodically, the combustion tube is bypassed, and the sample gas is passed directly through the NDIR. This is done to measure the sample background concentration of CO_2 . The difference between the CO_2 concentrations in these streams is the TOC concentration in the sample. The ST-7 results are accurate because the NDIR analyzer is calibrated with CO_2 , which is also the gas being measured.

The EPA Method 25A uses a flame ionization detector (FID) to analyze the TOC concentration in the sample gas (3). The FID is sensitive to the total hydrocarbon concentration in the sample stream, and does not distinguish between organic species. Thus, to correctly assess the VOC concentration in the sample, the components and the relative concentrations of the components in the sample stream must be known.

Furthermore, the FID is calibrated with propane, which may have a detector response factor which differs from the response factors of the organics being analyzed in the sample stream. In addition, the presence of oxygenated organic compounds in the FID will cause the organic carbon concentration to be underpredicted. These operational constraints cause Method M25A to be less quantitative (although more sensitive) than Method ST-7. Method M25A data is therefore used primarily as a check of the ST-7 data. A comparison of Tables 9 and 10 shows that, although the recorded concentrations are different, the trends are the same.

The results of the EPA Method 25A and BAAQMD Method ST-7 sampling trains are presented in Tables 9 and 10. Large, square communication shelters were painted during all of these sampling intervals. Most of the paint adhered to the large flat surfaces of the shelter, and was not dispersed into the air. The results of mass balance calculations, based on the ST-7 data and the paint usage records, are also presented in Table 10. The VOC concentration detected in the stack is within 60 percent of the predicted concentration determined from paint-usage data. For a description of how these calculations were done, see Appendix A.

The VOC concentrations detected in Stack 1 on June 4 between 945 and 1045 were almost zero because the paint operation took place at the opposite end of the booth in Quadrants 2 and 4. When painting commenced in Quadrants 1 and 3, the VOC level increased to 540 ppm carbon. During the

TABLE 9. M25A RESULTS -- McCLELLAN AIR FORCE BASE

Day	Site	Time interval	Sample time (min)	Paint time (min)	Quadrant	Peak (ppm ^a)	Background organic carbon (ppm)	Approximate average (ppm ^b)	Integrated total (ppm ^b min)
June 3	Stack 1 Quad 1	1000-1015	15	0	0	158	12	93	1,410 ^c
		1015-1030	15	5	2,4	66	12	36	408
		1030-1045	15	13	1,3	116	12	36	462
		1045-1100	15	11	1,3	93	12	48	642
		1100-1115	15	0	0	42	12	24	354 ^d
		1240-1255	15	4	2,4	95	12	51	852
		1255-1310	15	12	2,4	83	12	54	795
		1310-1325	15	14	1,3	98	12	63	954
				7	2,4				
		1325-1340	15	4	2,4	60	12	42	618
		1425-1440	15	9	1,3	66	12	37	684
		1440-1455	15	9	1,3	150	12	78	1,110
		1455-1510	15	6	1,3	201	12	87	1,266
		1536-1540	Fans Off: 4 Minutes			60	12	42	150
		1540-1542	Fans On: 2 Minutes			264	12	168	402
		1542-1542:30	Fans Off: 30 Seconds			144	12	122	0
		1542:30-1544	Fans On: 1.5 Minutes			270	12	198	366
		1544-1544:30	Fans Off: 30 Seconds			141	12	129	63
		1544:30-1547	Fans On: 2.5 Minutes			327	12	222	513
		1547-1556	Fans Off: 9 Minutes			84	12	54	327 ^e
June 4	Stack 1 Quad 1	0915-0930	15	2	2,4	15	6	6	129
		0930-0945	15	7	2,4	17	6	9	122
		0945-1000	15	7	2,4	17	6	7	123
		1000-1015	15	6	2,4	17	6	9	123
		1015-1030	15	7	2,4	17	6	10	159
		1030-1045	15	6	2,4	60	6	18	261
				1	1,3				
		1045-1100	15	7	2,4	33	6	18	198
June 4	Stack 4 Quad 2			4	1,3				
		1100-1110	10	7	2,4	15	6	6	57
		1245-1300	15	5	2,4	6	6	0	0
		1300-1315	15	5	2,4	6	6	0	0
		1315-1330	15	6	1,3	6	6	0	0
				7	2,4				
		1330-1345	15	4	1,3	6	6	0	0
				2	2,4				
June 5	Stack 3 Quad 2	1345-1352	7	0	0	6	6	0	0
		0845-0900	15	0	0	8	6	0	0
		0900-0915	15	0	0	6	6	0	0
		0915-0930	15	0	0	27	6	2	15
		0930-0945	15	0	0	20	6	3	30
		0945-1000	15	6	2,4	39	6	12	156
		1000-1015	15	5	2,4	36	6	9	138

^appm refers to carbon.^bppm refers to carbon concentrations minus the background levels.^cNo painting occurred at this time. Sharp peaks are due to spray gun cleaning.^dAt 11:20, the carbon concentration (10 ppm) was close to the background (6 ppm).^eNote the difference: Fans on for 2.5 minutes produced a count of 543 ppm minutes; fans off for 9 minutes produced a count of 435 ppm minutes.

TABLE 10. ST-7 RESULTS -- McCLELLAN AIR FORCE BASE

Day	Site	Time interval	Sample time (min)	Paint time (min)	Quadrant	Peak (ppm ^a)	Background CO ₂ (ppm)	Approximate average (ppm ^b)	Integrated total (ppm min)	Air flowrate (lpm)	Mass of carbon (Kg)	Amount of paint used (Kg)	Approximate mass of carbon in stack
June 4	Stack 1 Quad 1	0945-1000	15	7	2, 4	425	425	0	0	219,800	0.00		
		1000-1015	15	6	2, 4	425	425	0	0	219,800	0.00		
		1015-1030	15	7	2, 4	425	425	0	0	219,800	0.00		
		1030-1045	15	6	2, 4	425	425	0	0	219,800	0.00		
		1045-1100	15	7	2, 4	540	425	<50	240	219,800	0.0288		
		1100-1110	10	4	1, 3	550	425	<50	90	219,800	0.0108		
Total:										0.0396 ^b	0.63	0.092	
June 4	Stack 4 Quad 2	1245-1300	15	5	2, 4	400	400	0	0	226,200	0.00		
		1300-1315	15	5	2, 4	400	400	0	0	226,200	0.00		
		1315-1330	15	6	1, 3	400	400	0	0	226,200	0.00		
		1330-1345	15	4	1, 3	400	400	0	0	226,200	0.00		
		1345-1352	7	2	2, 4	400	400	0	0	226,200	0.00		
		0845-0900	15	0	0	400	400	0	0	200,600	0.00		
June 5	Stack 3 Quad 2	0900-0915	15	0	0	400	400	0	0	200,600	0.00		
		0915-0930	15	0	0	500	400	<50	120	200,600	0.0128		
		0930-0945	15	0	0	475	400	<50	480	200,600	0.0511		
		0945-1000	15	8	2, 4	475	400	50	810	200,600	0.0863		
		1000-1004	15	3	2, 4	450	400	50	180	200,600	0.0192		
		Total:										0.1694	2.43

ppm refers to carbon.

bpm refers to carbon concentration minus the background levels.

sample interval 1100 to 1110, the VOC concentration increased to 550 ppm carbon from 540 ppm, although no paint was being applied. This was undoubtedly due to the VOCs which came off the piece as it dried. Due to the large flat surface of the shelters, it was expected that VOC emissions from the booth would continue for some time after the painting process was stopped.

The VOCs detected in the 915 to 945 time interval on June 5 (when no painting activity was recorded) may be due to paint and equipment preparation (such as mixing the paint and cleaning the spray guns with solvents).

The sampling interval from 1536 to 1540 on June 3 illustrates the effect that fan operation has on VOC buildup in the spray booth. If the fans are turned off after a painting session, the VOC concentration in the booth increases very rapidly due to the drying paint. When the fans are turned on again, a high VOC concentration is detected in the stack. This is further illustrated in Figure 2 which is a plot of VOC concentration versus time in the booth while the fans were alternately turned on and off. These measurements indicate that dangerously high VOC concentrations can accumulate in a spray booth if the ventilation fans are turned off while pieces are drying in the booth.

The sample intervals and volumes used in the NIOSH 1300 tests are presented in Table 11, along with the results of speciation analyses performed on each charcoal tube. Unfortunately, the sampling times were too short for the NIOSH tubes used. The concentrations of many of the compounds expected to be found on the filters were below the detection limits of the GC-FID used in the analysis. However, sufficient data were acquired to draw several conclusions. The hydrocarbon concentration in the paint booth is highest in the vicinity of where the paint process occurs. This is exemplified by the data from tube 905399. The highest hydrocarbon concentration detected was found on this charcoal tube, which was located in the spray booth within 5 feet of where the paint was applied. The water curtain does not reduce the VOC emissions from the booth. VOCs were found on tube 905418 located in Stack 1, even though painting took place in Quads 2 and 4. No VOCs were detected in the other stack samples because little or no paint was applied during the sample intervals.

4. Particulate Concentration Measurements

Two test series were used to obtain particulate emissions data:

- The EPA M115 particulate and organics train was used to measure particulate levels in the exhaust ducts.
- The NIOSH Nuisance Dust method (NIOSH 500) was used to measure particulate levels in the exhaust ducts and in the spray booth.

These procedures are discussed more fully in Appendix C.

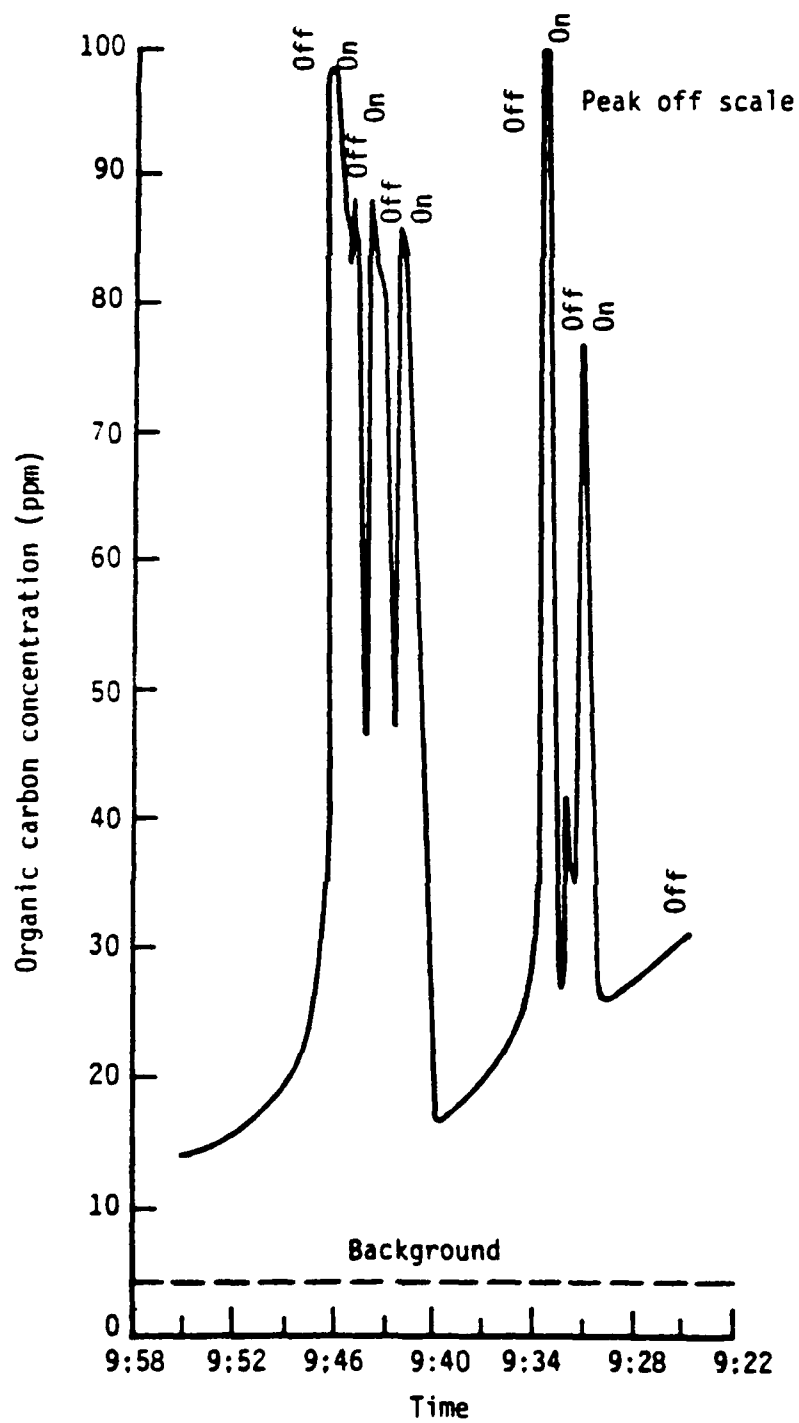


Figure 2. Variation of VOC Concentration as a Function of Fan Operation.

TABLE 11. NIOSH 1300 RESULTS -- McCLELLAN AIR FORCE BASE

Sample tube number	Date	Time	Site	Quadrant	Volume sampled (L @ STP)	VOC's detected ^a (mg)
905389	June 3	1649-1755	Background		3.33	ND
905390	June 3	1715-1758	Stack 3	2	2.25	ND
905396	June 4	0937-1023	Stack 1	1	2.91	ND
905359	June 4	1104-1209	Stack 4	2	4.08	ND
905401	June 4	1235-1351	Grate 15	2	0.61	ND
905398	June 4	1240-1400	Stack 4	2	5.36	ND
905399	June 4	1250-1444	Grate 14	3	7.41	0.04 Toluene 0.036 Butyl acetate 0.038 2-Butoxy ethanol
905415	June 5	0957-1056	Grate 15	2	2.16	0.013 2-Butoxy ethanol
10	June 5	0954-1051	Stack 1	1	3.52	0.025 2-Butoxy ethanol

^aDetection limit is 0.004 mg/tube.

The particulate data from the MM5 sampling train are presented in Table 12. The peak particulate emission rate was found to be about 0.5 mg/ft³, which corresponds well with the NIOSH 500 data.

The volume sampled and the mass of particulate collected in the NIOSH 500 tests are listed in Table 13. As can be seen from the table, filter data taken from the exhaust ducts indicate that very little particulate escapes the water curtain. Although paint was applied in the quadrants corresponding to the ducts under consideration, very little particulate was collected. This is exemplified by the filter data taken from Sites 1 through 8.

The particulate concentration inside the spray booth depended on where the paint was applied. For example, Filters 15 and 30 were placed at the sump grates on the opposite side of the booth from where a shelter was being painted. Little or no particulate was detected on these filters, which would indicate little crossflow in the booth. The particulate concentration in the quadrant where paint was being applied was significantly higher than anywhere else. For example, the mass of particulate collected on Filter 29 was significantly greater than the other filters because it was placed at a grate next to where a shelter was being painted.

5. Water Sampling

The water samples drawn from the sumps were analyzed for TOC, residue and organic species. The results of the TOC analysis presented in Table 14 indicate that, although a large quantity of organic compounds were trapped in the sump, a large quantity were also released. Due to the high rate of water evaporation, the sumps were refilled almost daily with 10 to 15 inches of makeup water (at least 1,000 liters/day per sump). The organics trapped in the water would likewise evaporate. The rate at which organic compounds evaporate depends on the water temperature and the solubility of the compounds in water.

It was not possible to do an accurate mass balance and include the TOC concentration in the water because paint operations continued 24 hours a day. Unless paint usage is continuously monitored, the amount of paint used versus the amount of organics trapped by the water cannot be quantified. A review of the TOC data indicates that after June 3, a relatively steady state TOC concentration was reached. This implies that the quantity of organic compounds trapped by the water curtain is approximately equal to the amount released. It may not be necessary, therefore, to take the amount of organics removed from the air by the water curtain into consideration when computing a mass balance for the system, because an approximately equal amount is replaced.

The results of volatile and semivolatiles analyses of the water in the sumps are presented in Tables 15 and 16. It is evident that, although the concentrations varied somewhat from sump to sump and from day to day, the essential compounds remained the same.

TABLE 12. MMS PARTICULATE SAMPLING RESULTS -- McCLELLAN AIR FORCE BASE

Date	Time	Sample site	Stack gas moisture (percent)	Stack gas temperature (°F)	Sample volume (cf @ STP)	Volumetric flowrate (scfm)	Particulate weight (±0.0005g)	Particulate concentration (mg/m ³)	Particulate emission rate (g/min)
June 3	1018-1118	Exhaust Vent 2	1.5	64	31.16	10,456	0.0166	18.73	5.57
June 3	1430-1530	Exhaust Vent 2	1.5	64	35.01	10,898	0.0096	9.68	2.99

TABLE 13. NIOSH 500 RESULTS -- McCLELLAN AIR FORCE BASE

Filter number	Date	Time	Site	Quadrant	Volume sampled (L @ STP)	Particulate on filter (mg) ^a	Mass (mg) particulate per m ³
3	June 1	1348-1504	14	3	116.15	0.06	0.5
12	June 1	1351-1504	13	1	114.99	0.0	0.0
10	June 2	0834-1104	16	4	115.94	0.0	0.0
5	June 2	0838-1100	15	2	110.27	0.0	0.0
16	June 2	0956-1114	1	1	60.44	0.05	0.8
2	June 2, 3	1252-1316	4	2	148.05	0.0	0.0
		1355-1405					
		1020-1106					
7	June 3	0927-1117	5	3	106.07	0.05	0.5
13	June 3	1021-1110	8	4	111.85	0.0	0.0
21	June 3	1236-1344	4	2	109.63	0.0	0.0
20	June 3	1427-1535	5	3	118.04	-0.07 ^b	
6	June 3	1422-1530	4	2	110.73	0.0	0.0
30	June 4	0807-0940	14	3	149.28	0.06	0.4
29	June 4	0955-1124	15	2	232.04	0.4	1.7
15	June 4	0959-1118	14	3	126.83	0.0	0.0

^aFilter weights are to ± 0.04 mg.

^bA small piece was torn from the filter when it was removed from the filter holder, thus making this test invalid.

TABLE 14. TOC RESULTS -- McCLELLAN AIR FORCE BASE

June 3

	Sample number and site				
	905375 Sump 9	905379 Sump 10	905380 Sump 11	905381 Sump 12	905378 Blank
TOC (mg/L)	77	140	27	240	<1
Depth (in.)	19.5	15.9	20.8	16	
Volume (L)	6,323	5,158	6,748	5,191	
TOC per Sump (mg)	486,871	722,120	182,196	1,245,840	

June 4

	Sample number and site				
	905391 Sump 9	905392 Sump 10	905393 Sump 11	905394 Sump 12	905395 Blank
TOC (mg/L)	200	110	97	230	<1
Depth (in.)	20.25	18.5	17.13	16.75	
Volume (L)	6,570	6,002	5,557	5,434	
TOC per Sump (mg)	1,314,000	660,220	539,029	1,249,820	

June 5

	Sample number and site			
	905405 Sump 9	905409 Sump 10	905411 Sump 11	905408 Sump 12
TOC (mg/L)	190	57	37	170
Depth (in.)	23.81	25.25	28.25	17.63
Volume (L)	7,725	8,192	9,165	5,720
TOC per Sump (mg)	1,467,750	466,944	339,105	972,400

TABLE 15. VOLATILE COMPOUND ANALYSIS EPA 624 -- McCLELLAN AIR FORCE
BASE

June 2

Compound ($\mu\text{g/L}$)	Sample number and site				
	905470 ^a Sump 9	905469 Sump 10	905472 ^a Sump 11	905474 Sump 12	905368 ^a Make-up
Toluene		360			
Ethylbenzene					
Acetone					
2-Butanone		10,336	784	5,400	
4-Methyl-2-pentanone		36			
Total Xylenes	2	137			
2-Butoxy ethanol		8		340	
Polyethelene glycol- mono ethanol amine		230		10,000	2,500

June 5

Compound ($\mu\text{g/L}$)	Sample number and site			
	905402 Sump 9	905404 Sump 10	905412 Sump 11	905413 Sump 12
Methylene chloride	16	25	14	14
Toluene	18			53
Ethylbenzene	2			3
Acetone	200	720	210	310
2-Butanone	2,400	11,000	540	8,800
4-Methyl-2-pentanone	7	38	13	100
Total Xylenes	11		1	40

^aSamples were diluted prior to analysis. The resulting concentrations of several compounds were therefore too low to detect.

TABLE 16. SEMIVOLATILE COMPOUND ANALYSIS EPA 625 -- McCLELLAN AIR
FORCE BASE

June 2

Compound ($\mu\text{g/L}$)	Sample number and location				
	905370 Sump 9	905369 Sump 10	905372 Sump 11	905374 Sump 12	905368 Makeup
Phenol	5	7		8	
Di-n-butyl phthalate		11			8

June 5

Compound ($\mu\text{g/L}$)	Sample number and location			
	905397 Sump 9	905403 Sump 10	905410 Sump 11	905407 Sump 12
Di-n-butyl phthalate	14			

TABLE 17. WATER RESIDUE RESULTS -- McCLELLAN AIR FORCE BASE

June 2

	Sample number and location					
	DI Water Blank	905370 Sump 9	905369 Sump 10	905372 Sump 11	905374 Sump 12	905368 Makeup
Initial volume (mL)	100	100	100	100	100	100
Final weight (g)	44.3410	48.9444	49.4512	48.7672	41.7661	49.7500
Evaporative dish tare (g)	44.3402	48.8819	49.3850	48.7058	41.6750	49.7269
Residue weight (mg)	0.8	62.5	65.95	61.4	91.1	23.1
Total residue (g/L)	0.008	0.625	0.6595	0.614	0.911	0.231

June 5

	Sample Number and location				
	DI Water Blank	905397 Sump 9	905403 Sump 10	905410 Sump 11	905407 Sump 12
Initial volume (mL)	100	100	100	100	100
Final weight (g)	44.3410	47.1731	46.7715	41.7374	49.2335
Evaporative dish tare (g)	44.3402	47.1161	46.7345	41.6869	49.1515
Residue weight (mg)	0.8	57.0	37.0	50.5	82
Total residue (g/L)	0.8	0.570	0.370	0.505	0.82

Total residue analyses were also performed on the water samples, the results of which are given in Table 17. At first glance, it appears that the residue concentration (comprised mainly of paint particles) decreases as a function of time. The June 2 samples were taken during the lunch break, after a considerable amount of painting was done. The samples taken on June 5 were drawn early in the morning, before the water curtain pumps were turned on. There was no painting in the 8 hours before sampling, so a considerable amount of particulate may have settled to the bottom of the sump. Although the sump water was stirred before a sample was drawn, it is possible that an even distribution of particulate was not achieved. Because of the low particulate concentrations found in the stacks, and the high particulate concentrations detected in the sump water, it is apparent that the water curtain does remove particulate from the air stream.

In summary, at the McClellan Air Force Base paint facility in Building 655, the peak VOC concentrations were 550 ppm (see Table 10). Particulate concentrations inside the booth were 1.7 mg/m^3 (see Table 13), and particulate concentrations outside the booth were 0.78 mg/m^3 (see Table 13). The highest estimated VOC emission rate was 0.95 mg/m^3 as carbon (see Table 10).

B. TRAVIS AIR FORCE BASE -- BUILDING 550

A schematic of the Building 550 paint spray booth at Travis Air Force Base is shown in Figure 3. Initially, a small room used for fiberglass applications next to the paint spray booth was included in the study. When it was found that the room was separate from the spray booth (with its own ventilation system), it was decided not to include the fiberglass room. The painting compartment in this facility is approximately 75 feet long and 50 feet wide, and is subdivided into two sections by a 3-foot wide partition. Outside air is drawn through a series of particulate filters, and ducted into the front of the room through ceiling vents. The air flows down and across the room, then passes through particulate filters which cover the back wall of each of the booths (these filters clogged fairly rapidly, and were generally changed every 1 or 2 days). The air is then ducted out of the room and exhausted through a series of four roof stacks. Radial fans within each stack draw the air through the filters on the back wall of the booth. No VOC control devices are in place at this facility. The sampling locations are listed in Table 18 and included in Figure 2.

1. Paint Processes and Usage

Samples of paints to be used for the duration of the test were taken and analyzed for residue, volatile and semivolatile contents. The results were used to aid in organic speciation analyses of VOC compounds found in the air sample. Table 19 lists the primary components of the paints. In addition, Table 20 presents results of the paint residue analysis.

As with the McClellan facility, it was anticipated that the particulate and organic concentrations would depend on where in the room the paint was applied, as well as the orientation of the surface being painted.

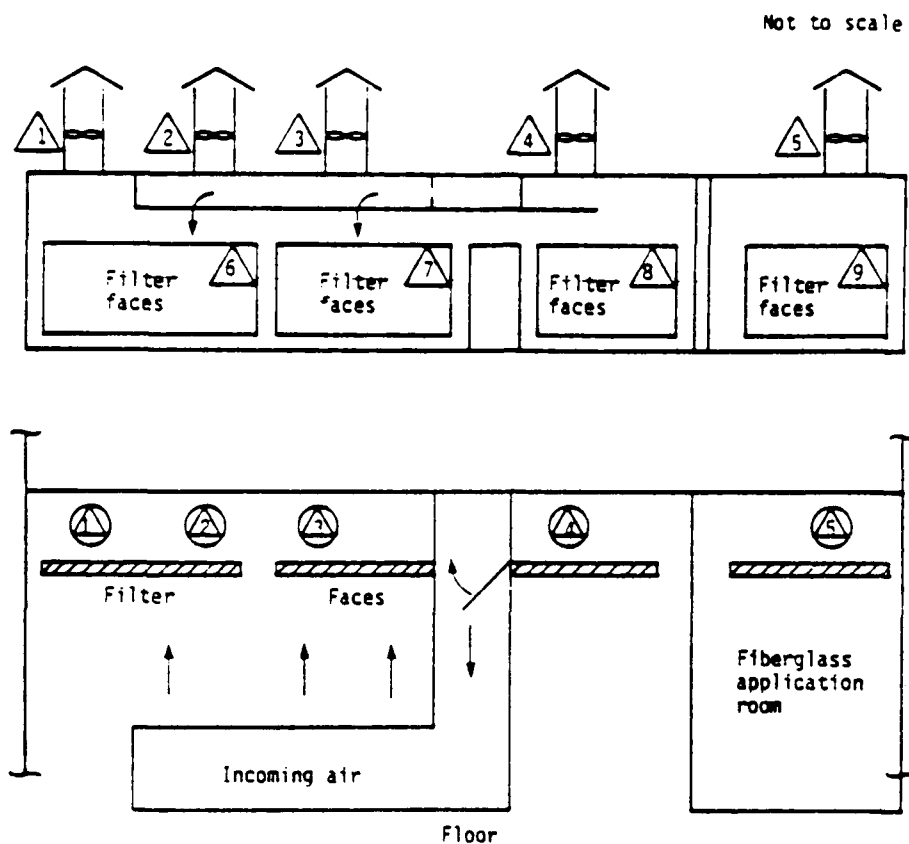


Figure 3. Schematic of Paint Spray Booth -- Travis Air Force Base, Building 550.

TABLE 18. SAMPLING LOCATIONS --
TRAVIS AIR FORCE BASE,
BUILDING 550

Location number	Description
1	Exhaust stack
2	Exhaust stack
3	Exhaust stack
4	Exhaust stack
5	Exhaust stack
6	Filter face
7	Filter face
8	Filter face
9	Filter face

TABLE 19. GC/MS ANALYSIS OF PAINT SAMPLES -- TRAVIS AIR FORCE BASE

Compound (mg/L)	Sample Numbers ^a									
	905416	905417	905423	905424	905425	905427	905429	905432	905433	
1,1,1-Trichloroethane				400			500			
Trichloroethene							250			
Toluene				48,000	3,050	350		58,000	65,000	
Ethylbenzene	50	11,500	7,000		100	300		1,550	900	
Acetone							600			
2-Butanone	130,000	~300,000			b>650,000			102,500	~350,000	
Propylacetate				>105,000						
Butyl acetate	>41,000									
3-Methylhexane										
4-Methyl-2-pentanone	55,000	500		10,000				22,500	10,500	
Cyclohexanone	50	62,500								
Total Xylenes	400	66,500	31,500	100	450	1,650		7,000		
2-Propanol			>105,000			>115,000	>140,000	>85,000	28,500	
Unknown #427						65,000				
Unknown #295			>65,000					19,000	9,000	
Unknown #329									>65,000	
Unknown #427										
Unknown #437										
Unknown #448				17,500				11,500		
Unknown #455								14,000	>135,000	
Unknown #477										

^aThe sample numbers correspond to the following paints:

905416	MIL-C-83286D Green Part 1	905427	DOD-C-153280 Wash Primer Part 1
905417	MIL-C-83286B Green Part 2	905429	DOD-C-1532810 Wash Primer Part 2
905423	MIL-P-23377D Yellow Primer Part 1	905431	MIL-P-79620 Cellulose Nitrate Primer
905424	MIL-P-23377D Yellow Primer Part 2	905433	MIL-T-P1772A Polyurethane Thinner
905425	TT-H-2610 Thinner (MEK)		

^bLower bound values indicate that the concentration of this compound was too high, and therefore saturated the mass spectrometer.

TABLE 20. RESIDUE ANALYSIS OF PAINT SAMPLES --
TRAVIS AIR FORCE BASE

Sample	Paint type	Initial weight (g)	Final weight (g)	Percent Volatile
905425	MEK	0.5381	0.00	100
905431	Cellulose nitrate	0.4066	0.063	84.5
905433	Poly thinner	0.3086	0.00	100
<u>Mixtures</u>				
905416	Poly green	0.7733	0.3586	53.6
905417				
1:1				
905423	Yellow primer	0.8472	0.4448	47.5
905424				
1:1				
95427	Wash primer	0.4692	0.0420	90.9
95429				
4:1				

For this reason, the facility was considered to be divided into three sections associated with the three filter faces located at the back of the booths. Records were kept of where, in terms of these sections, the paint was applied, as well as the time and rate at which the paint was consumed. These records are summarized in Tables 21 and 22. The particulate and organic sampling results, discussed in subsequent sections, are correlated with these records.

2. Flow Measurements

Daily anemometer readings were taken at each of the three filter faces. The faces were divided into 10 by 10-inch sections, and flow measurements were taken over each section. The results of the integrated flow calculations are presented in Table 23.

The results of the EPA Method 2 volume flow measurements are given in Table 24. Unfortunately, radial fans located in the stacks immediately upstream of where the measurements were taken, caused the flow to be highly nonlaminar. As with the McClellan data, vortical flow and recirculation were often detected with the pitot tube. If a negative pressure differential was encountered, a zero value was substituted to overpredict the volume flow.

The large discrepancy between the anemometer data and Method 2 volume flow measurements can be largely explained by the fact that considerable in-leakage occurred behind the filter faces at the junction with the exhaust ducts. As the filters became clogged, the airflow was reduced, resulting in outside air being drawn through the stacks.

3. VOC Measurements

The results of the organic module analysis of the MM5 tests are presented in Table 25. During the Test 1 sample interval, 46 minutes of painting took place in Section 2, which corresponds to Stacks 1 and 2. The long painting interval reflects the high organic concentration detected in Stack 2. During Test 2, 16 minutes of painting took place which explains the significantly lower VOC concentrations. During Test 3, no painting took place in Section 3 (which corresponds primarily to Stack 4), thus, the organics concentration detected by the MM5 sample train was negligible. During Test 4, there was only 5 minutes of painting in front of Stack 1, which explains the low semivolatiles concentrations detected.

The results of the EPA Method 25A and BAAQMD Method ST-7 sampling trains are shown in Tables 26 and 27. A variety of field pieces and engine parts were painted during these sampling times; generally they were pieces with large planar surface areas. Most of the paint adhered to surfaces, and was not dispersed into the air. The results of mass balance calculations based on the ST-7 and NIOSH 1300 speciation data and the paint usage log are presented in Table 27. Agreement between the amount of paint used during the sampling interval and the amount of hydrocarbons detected by the ST-7 sampling train is within 35 percent.

TABLE 21. PAINT BOOTH OPERATING LOG -- TRAVIS AIR FORCE BASE,
BUILDING 550

Date	Time	Section	Paint time (min)	Comments
June 16	1005-1008	N1 ^a	3	3 coats of anticorrosion compound
	1117-1124	2	7	1 operator; under stack three
	1130-1140	2	10	1 operator; under stack three
	1142-1150	2	8	1 operator; under stack three
	1152-1202	2	10	2 operators; under stack three
	1203-1211	2	8	2 operators; under stack three
	1212-1217	2	5	1 operator; under stack three
	1225-1226	1	1	1 operator; under stack three
June 17	1735-1835	2	60	1 operator; sanding
	0934-0936	1,2	2	1 operator; door
	0941-0946	1	5	1 operator; chairs
	0942-0945	2	3	1 operator; nose cone, small parts
	0951-0953	2	2	1 operator; nose cone, small parts
	0956-1028	1	32	1 operator; chairs
	0956-0958	1,2	2	1 operator; door
	1008-1011	2	3	1 operator; nose cone, small parts
	1019-1021	2	3	1 operator; nose cone, small parts
	1036-1039	2	3	1 operator; nose cone, small parts
	1445-?	2	5	Sanding
	1640-1650	2	10	Sanding chairs, ladders and other parts
	1650-1705	1	15	Ladders and chairs
	1713-1732	1	19	1 operator; ladder and chairs
	1740-1747	1	7	1 operator; ladder and chairs
	1732-1741	2	9	1 operator; small parts
	1756-1809	2	13	1 operator; small parts
	1818-1820	2	2	1 operator; small parts
June 18	0930-0934	1	4	Paint mixing; quad 1
	0934-0938	1	4	1 operator; small piece
	0947-0949	1	2	1 operator; small piece
	0936-0947	2	11	2 operators; C5 engine intake
	1005-1026	2	21	2 operators; C5 engine intake
	1012-1015	1	3	1 operator; small parts
	1431-1433	1	2	Mixing primer
	1433-1447	2	14	1 operator; fuselage and cabinet
	1452-1510	2	18	1 operator; fuselage and wing
June 19	0812-?	1	N1	Mixing primer
	0835-0848	1	13	2 operators; cabinet
	0851-0858	1	7	2 operators; cabinet
	0945-?	1	N1	Mixing polyurethane
	0952-1020	2	28	2 operators; C141 engine

^aNo information.

TABLE 22. PAINT USAGE LOG -- TRAVIS AIR FORCE BASE, BUILDING 550

Date	Time	Section	Paint type	Amount used (Kg)	Comments
June 16	1117-1124	2	Primer	0.02	1 operator, under stack three
	1130-1226	1,2	Yellow 23531	2.04	2 operators, under stack three
June 17	0941-0946	1	Primer	0.36	1 operator, troop chairs
	0956-1028	1	Yellow 23531	1.47	1 operator, troop chairs
	0934-0958	1,2	Green primer	0.82	1 operator, door between quads 1 & 2
	1008-1039	2	White epoxy	0.91	1 operator, nose cone & small parts
	1650-1705	1	Primer	0.91	2 operators, ladders and pilot chairs
	1740-1747	1	Tan lacquer	1.02	2 operators, pilot chairs
	1740-1747	1	Green lacquer	0.45	1 operator, ladders
	1732-1741	2	Primer	0.79	1 operator, small parts
	1756-1809	2	Gunship color epoxy	1.02	1 operator, small parts
	1816-1820	2	Polyurethane green	0.23	1 operator, small parts
June 18	0934-0949	1	Yellow primer	0.68	1 operator, field piece
	0936-0947	2	Yellow primer	1.36	2 operators, C5 engine guard
	1005-1026	2	Polyurethane green	2.38	2 operators, C5 engine guard
	1012-1015	1	Polyurethane green	0.68	1 operator, small parts
	1433-1447	2	Yellow primer	0.79	1 operator, fuselage
	1452-1510	2	Polyurethane gray	2.15	1 operator, fuselage & wing
June 19	0835-0848	1	Yellow primer		2 operators, cabinet
	0851-0858	1	Yellow primer	3.97 ^a	2 operators, cabinet
	0945	1	Polyurethane green		Mixing polyurethane green
	0952-1020	2	Polyurethane green	3.63	2 operators, C-141 engine

^aThis is the total amount used from 8:35 to 8:58.

TABLE 23. VOLUMETRIC FLOWRATE ANEMOMETER DATA -- TRAVIS AIR FORCE BASE,
BUILDING 550

Site	June 15	June 16	June 17	June 19
Filter 6	17911	20583	21392	17578
Filter 7	22381	20194	22456	25614
Filter 8	7092	8206	10636	21011
Total (cfm)	47,384	48,983	54,484	64,203
Temperature (°F)	70	70	66	70
Barometric pressure (in. Hg)	30	29.9	30	29.9
Total (cfm @ STP)	47,339	48,937	54,846	64,099
Total (Lpm @ STP)	1,339,693	1,384,917	1,552,141	1,814,002

TABLE 24. VOLUMETRIC FLOWRATE EPA METHOD 2 --
TRAVIS AIR FORCE BASE, BUILDING 550

Site	Volume flow (cfm @ STP)	
	June 15	June 16
Stack 1	15,150	16,239
Stack 2	16,285	20,100
Stack 3	11,690	11,159
Stack 4	<u>13,950</u>	<u>10,679</u>
Total:	57,075	58,177
Total (Lpm @ STP)	1,615,222	1,646,409
Percent difference:	1.9	

TABLE 25. MM5 ORGANICS SAMPLING RESULTS -- TRAVIS AIR FORCE BASE,
BUILDING 550

	Test 1	Test 2	Test 3	Test 4	Blank
Date	6-16-87	6-17-87	6-17-87	6-18-87	
Time	1115-1218	940-1040	1700-1800	940-1040	
Site	Stack 2	Stack 2	Stack 4	Stack 1	
Volume sampled (CF @ STP)	43.561	25.473	39.922	42.859	
Volume sampled (L @ STP)	1,234	721.5	1,131	1,214	
Semivolatile compounds detected (ug/sample)					
Phenol	0	34	0	2	0
Naphthalene	6	5	3	5	3
Diethylphthalate	65	49	39	23	12
N-Nitrosodiphenylamine	17	17	14	7	11
Di-n-butylphthalate	6	4	0	3	7
Butylbenzylphthalate	2	2	0	2	2
bis(2-ethylhexyl)phthalate	17	14	5	7	0
Benzaldehyde	5	8	0	0	0
Ethylbenzene	280	130	0	28	0
1,3-Dimethylbenzene	670	260	37	85	0
1,2-Dimethylbenzene	280	150	0	34	0
2,4,6-Trimethyloctane	6	11	0	0	0
5-Methyl-2-furancarboxaldehyde	0	28	0	0	0
2-Hydroxy-benzaldehyde	0	9	0	0	0
Ester monohexanedioic acid (2-ethylhexyl)	34	16	0	0	20
Ethanol-2 (2-methoxyethoxy)	0	0	0	7	5
Ethyl-benzaldehyde	7	0	4	7	0
Alpha-oxo-benzeacetic acid	0	0	8	13	10
2-Chloro-1(4-ethylphenyl)-2-methyl-1-propanone	0	0	0	5	8
mol (58) sulfur	0	0	0	0	33
2-Cyclohexene-1-one	0	0	0	0	6
Decane	15	0	0	0	0
1-Ethyl-2-methyl-benzene	8	0	0	0	0
1,3,5-Trimethyl-benzene	6	0	0	0	0
Ethenylbenzene	0	0	120	0	0

TABLE 26. M25A RESULTS -- TRAVIS AIR FORCE BASE, BUILDING 550

Day	Site	Time interval	Sample		Section	Peak (ppm ^d)	Background organic carbon (ppm)	Approximate average (ppm ^b)	Integrated total (ppm ^b min)
			Time (min)	Paint time (min)					
June 17	Stack 2	1650-1705	15	15	1	77	1	41	559
		1705-1720	15	7	1	78	1	44	681
		1720-1735	15	12	1	111	1	56	653
				3	2				
		1735-1750	15	7	1	41	1	29	462
				9	2				
		1750-1805	15	9	2	36	1	56	142
		1805-1820	15	4	2	27	1	17	298
		1820-1829	9	0	0	13	1	8	117
June 18	Stack 2	0934-0945	11	11	1	71	2	37	466
				9	2				
		0945-1000	15	4	1	49	2	16	258
				2	2				
		1000-1015	15	3	1	64	2	49	668
				10	2				
		1015-1030	15	10	2	79	2	55	834
		1030-1045	15	0	0	27	2	13	179
		1045-1100	15	0	0	8	2	5.5	73
		1100-1115	15	0	0	5	2	2.5	35
June 18	Stack 3	1433-1445	12	12	2	215	3	39	421
		1445-1500	15	10	2	53	3	27	394
		1500-1515	15	10	2	89	3	54	801
		1515-1530	15	0	0	24	3	12	135
June 19	Stack 3	0815-0830	15	0	0	9	3	5	79
		0830-0845	15	10	1	9	3	5	68
		0845-0900	15	10	1	11	3	6	83
		0900-0915	15	0	0	11	3	7	108
June 19	Stack 1	0930-0945	15	0	0	24	3	7.5	109
		0945-1000	15	8	1	90	3	36	368
		1000-1015	15	15	1	161	3	80	1,095
		1015-1019	4	4	1	159	3	126	453

^appm refers to carbon.
^bppm refers to carbon concentration minus the background levels.

TABLE 27. ST-7 RESULTS -- TRAVIS AIR FORCE BASE, BUILDING 550

Day	Site	Time Interval	Sample time (min)	Paint time (min)	Section	Peak (ppm)	Background CO ₂ (ppm)	Approximate average (ppm)	Integrated total (ppm min)	Air flowrate (Lpm)	Mass of carbon (Kg)	Amount of paint used (Kg)	Approximate mass of carbon in stack (Kg)
June 18	Stack 2	0934-0945	11	11	1	650	300	175	1,020	514,800	0.283		
		0945-1000	15	9	2	575	300	100	1,380	514,800	0.383		
			15	4	1	575	300	100	1,380	514,800	0.383		
		1000-1015	15	2	2	625	300	200	2,580	514,800	0.716		
			15	3	1	625	300	200	2,580	514,800	0.716		
		1015-1030	15	10	2	575	325	150	1,800	514,800	0.499		
			15	10	2	400	325	50	1,170	514,800	0.324		
June 18	Stack 3	1030-1045	15	0	0	325	325	0	1,110	514,800	0.308		
		1045-1100	15	0	0	325	325	0	1,110	514,800	0.308		
		1100-1115	15	0	0	425	325	0	1,020	514,800	0.283		
			15	0	0	425	325	0	1,020	514,800	0.283		
										Total:	2.796	5.1	0.92
		1433-1445	12	12	2	675	400	75	840	323,300	0.146		
		1445-1500	15	10	2	525	400	25	360	323,300	0.062		
June 19	Stack 3	1500-1515	15	10	2	625	400	75	1,020	323,300	0.177		
		1515-1530	15	0	0	400	400	0	0				
			15	0	0	400	400	0	0				
										Total:	0.385	2.94	0.41
		0815-0830	15	0	0	400	400	0	0				
		0830-0845	15	10	1	400	400	0	0				
		0845-0900	15	10	1	400	400	0	0				
June 19	Stack 1	0900-0915	15	0	0	400	400	0	0				
										Total:	0	3.97	0
		0930-0945	15	0	0	450	400	25	180	514,800	0.049		
		0945-1000	15	8	1	675	400	75	1,060	514,800	0.294		
			15	15	1	675	400	100	1,460	514,800	0.405		
		1015-1018	4	4	1	575	400	100	340	514,800	0.094		
										Total:	0.842	3.63	1.0

ppm refers to carbon.
bpm refers to carbon concentration minus the background levels.

For reasons discussed in Section II.A.3, it was decided to base the VOC emission analysis on the ST-7 data. Although the M25A sample train is more sensitive, it is also less quantitative in this application. Figure 4 indicates the difference between M25A and ST-7 data. The plots are taken over the same time periods. As this diagram shows, the M25A sample train responds more quickly to variations in VOC concentrations. It is also better able to detect low VOC concentrations.

On June 18 between 0930 and 1030, a large field piece and a -C5 engine housing were painted in Sections 1 and 2. The ST-7 sample train was placed in Stack 2, which corresponds to both sections. As expected, the VOC concentrations were relatively high (the peak ST-7 value was 625 ppm carbon). Between 1030 to 1115, the VOC concentration remained high, despite the fact that no painting was taking place. This is most likely due to the hydrocarbons coming off the pieces as they dried. Note that the VOC concentration decreased as a function of time. During the sample interval 1433 to 1530, smaller pieces including a cabinet and part of a fuselage were painted. These pieces had a much smaller surface area, thus, a significant amount of the paint did not adhere to the surface when it was applied, and it diffused into the air. As expected, the VOC concentration was high (675 ppm carbon) during the painting interval. When painting stopped however, the VOC concentration dropped significantly. Unlike the larger field pieces painted earlier in the day, few VOCs were emitted while these pieces dried, because of the smaller surface area.

To investigate the dependency of VOC concentration on location in the spray booth, an ST-7 sample train was run at Stack 3 while paint was applied to cabinets in Section 1 (which correspond to Stacks 1 and 2). No VOC emissions were detected during this test, which indicates that hydrocarbon concentrations are low except near where paint and solvents are used.

The sampling intervals and volumes used in the NIOSH 1300 tests are presented in Table 28, along with the results of speciation analyses done on each charcoal tube. The hydrocarbon species data were used in the mass balance calculations described in the previous section.

Tubes 905457 and 905459 contained large concentrations of hydrocarbons (up to 0.026 mg/L of solvent) because they were sampling in sections where large amounts of paint were applied. Conversely, Tubes 905462 and 905463 were both sampling in sections which were at opposite ends of the room from where paint was applied. As expected, little or no VOCs were detected.

Tubes 905460 and 905461 were placed in front of the filter faces near where a piece of equipment was painted, but to keep the tubes out of the workmen's way, they were placed approximately 7 feet high. Despite the awkward placement, it was believed that large quantities of hydrocarbons would still be detected. Some hydrocarbons were collected, but not in the quantities anticipated. Tube 905460 collected only 0.0049 mg of solvent per

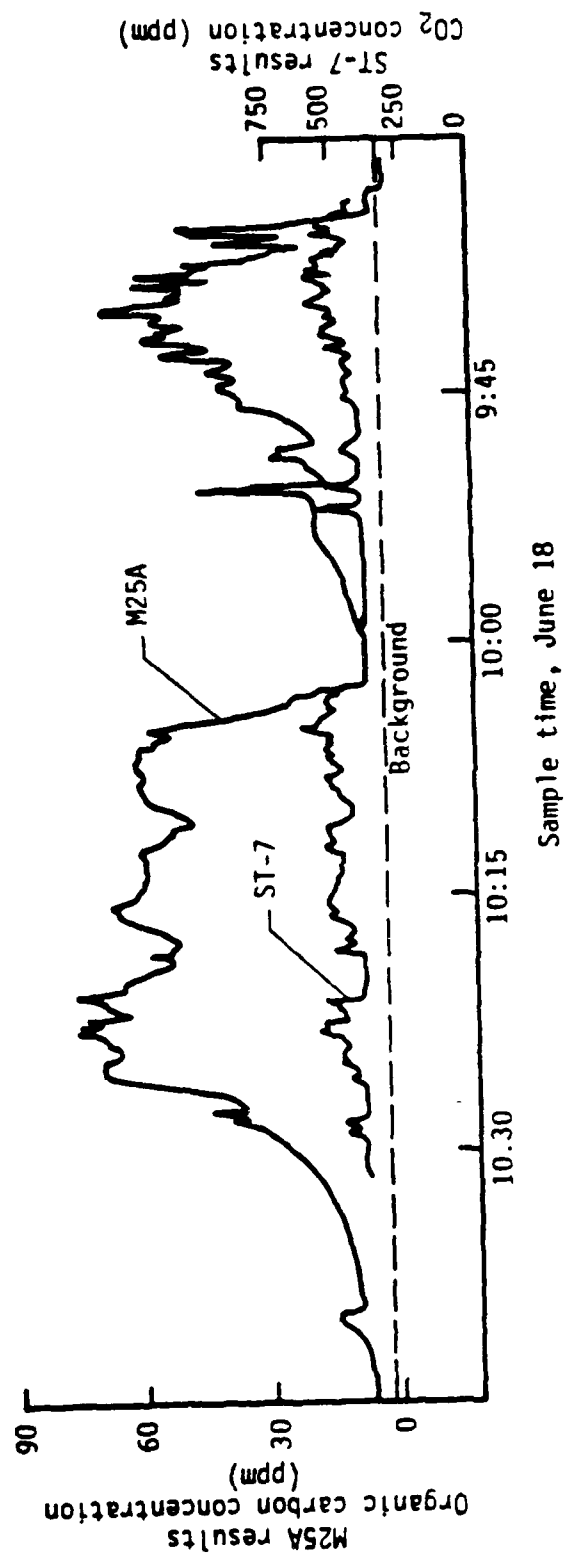


Figure 4. Comparison of M25A and ST-7 Data Taken Over the Same Timeframe.

TABLE 28. NIOSH 1300 RESULTS -- TRAVIS AIR FORCE BASE, BUILDING 550

Charcoal tube number	Date	Time	Site	Section	Volume sampled (L @ STP)	VOC's detected (mg)
905456	June 18		Outside Blank	1,2		ND ^a
905457	June 18	0931-1005	Stack 2	1,2	2.82	0.014 2-Propanol 0.013 Butyl acetate 0.012 Toluene
905458	June 18	1024-1059	Stack 1	1	2.85	0.005 Toluene 0.005 m-Xylene
905459	June 18	1425-1509	Stack 3	2,3	2.67	0.033 2-Propanol 0.01 Butyl acetate 0.009 Toluene 0.002 o-Xylene 0.002 m-Xylene 0.008 p-Xylene 0.007 4-Methyl-2-pentanone
905460	June 18	1437-1514	Filter 7	2	2.86	0.003 Butyl acetate 0.003 Toluene 0.001 o-Xylene 0.001 m-Xylene 0.006 4-Methyl-2-Pentanone
905461	June 19	0833-0901	Filter 6	1	1.96	0.001 Butyl acetate 0.001 Toluene
905462	June 19	0833-0900	Filter 8	3	3.3	ND
905463	June 19	0836-0908	Stack 4	3	2.27	ND
905464	June 19		Inside Blank			ND

^aND = Nondetectable. Detection limit is 0.5×10^{-3} mg/tube.

liter, while Tube 905461 collected particularly low hydrocarbon concentrations due to the low sample volume.

4. Particulate Concentration Measurements

The particulate data garnered from the MM5 sampling train is presented in Table 29. As the table shows, very low particulate concentrations were detected in the stack.

The volume sampled and mass of particulate collected in the NIOSH 500 tests are listed in Table 30. Although a large sample volume was drawn in each of the tests, little particulate was actually collected. The largest amount of particulate collected was on Filter 28 which was located in Stack 4 while a large piece was being sanded on the edge of Section 2 (near Section 3). At the same time, a filter was placed directly in front of Section 2 (Filter 7), yet no particulate was collected on it. The only plausible explanation is that the Filter 7, which was placed high up to keep it out of the workmen's way, was above the airstream carrying the particulate. The reason Filter 28 collected a considerable amount of particulate may be that the filter probe knocked loose some particulate from the inside of the stack. Considerable amounts of particulate were found encrusted on the walls of the stack. Filter 45 collected a detectable amount of particulate when it was placed between Sections 1 and 2 at a time of considerable painting activity in both of these sections.

In summary, at the Travis Air Force Base paint facility in Building 550, it was found that peak VOC concentrations were as high as 675 ppm (see Table 27). Particulate levels inside the booth were found as high as 2.5 mg/m^3 (see Table 30), and levels outside the booth were up to 4.4 mg/m^3 (see Table 30). This unusually high particulate concentration found in the stack may be due to particulate being collected from the cake which encrusted the stack walls. The highest estimated VOC emission rate was 13.8 mg/m^3 (see Table 27).

C. TRAVIS AIR FORCE BASE -- BUILDING 1014

A schematic of the Building 1014 paint spray booth at Travis Air Force Base is shown in Figure 5. The facility is a single booth measuring 60-feet long, 18-feet wide, and 18-feet high. Air is drawn through a series of particulate filters in the front faces and along the perimeter of both main doors. Air flows along the length of the room and passes through particulate filters which cover the back face of the booth. The air is then ducted out of the room through an exhaust vent passing directly to the exterior of the building. The unit is maintained under negative pressure to prevent VOC emissions from entering the surrounding hangar area, thus significant in-leakage may occur. There are no VOC emission control devices in place at this facility. The sampling locations are included in Figure 5.

TABLE 29. MM5 PARTICULATE SAMPLING RESULTS -- TRAVIS AIR FORCE BASE,
BUILDING 550

Date	Time	Sample site	Stack gas moisture (percent)	Stack gas temperature (°F)	Sample volume (cf @ STP)	Volumetric flowrate (scfm)	Particulate weight (±0.0005 g)	Particulate concentration (mg/m ³)	Particulate emission rate (g/min)
June 16	1115-1218	Exhaust Vent 2	1	76	43.56	20,100	0.0021	1.69	0.964
June 17	940-1040	Exhaust Vent 2	1.1	66	25.47	12,820	0.0021	2.90	1.051
June 17	1700-1800	Exhaust Vent 4	0.6	75	39.92	11,978	0.0006	0.530	0.180
June 17	940-1040	Exhaust Vent 1	0.4	64	42.86	20,693	0.0012	0.989	0.579

TABLE 30. NIOSH 500 RESULTS -- TRAVIS AIR FORCE BASE, BUILDING 550

Filter number	Date	Time	Site	Section	Volume sampled (L @ STP)	Particulate on filter (mg) ^a	Mass (mg) particulate per m ³
4	June 16	1201-1345	Filter 7	2	153.56	0.00	0.0
9		0933-1059	Stack 1	1	115.7	I ^b	
11		1016-1114	Stack 4	3	128.6	I	
14		1734-1830	Stack 1	1	92.4	0.00	0.0
28		1730-1824	Stack 4	3	83.6	0.37	4.4
44		1738-1834	Filter 7	2	84.9	0.00	0.0
18	June 17	1653-1829	Filter 8	3	150.4	I	
22		0943-1112	Filter 7	2	155.0	0.00	0.0
26		0940-1058	Stack 4	3	119.8	I	
27		0930-1056	Stack 3	2,3	130.2	0.00	0.0
36		1633-1802	Stack 3	2,3	138.8	0.00	0.0
39		1634-1813	Stack 2	1,2	152.31	0.00	0.0
35	June 18	1428-1540	Filter 6	2	110.9	I	
45		0924-1054	Filter 6,7	1,2	126.5	0.28	2.5
46		0936-1111	Stack 2	2	148.9	0.00	0.0

^aFilter weights are ± 0.05 mg.

^bInvalid sample -- filter was torn or altered when it was removed from sample holder.

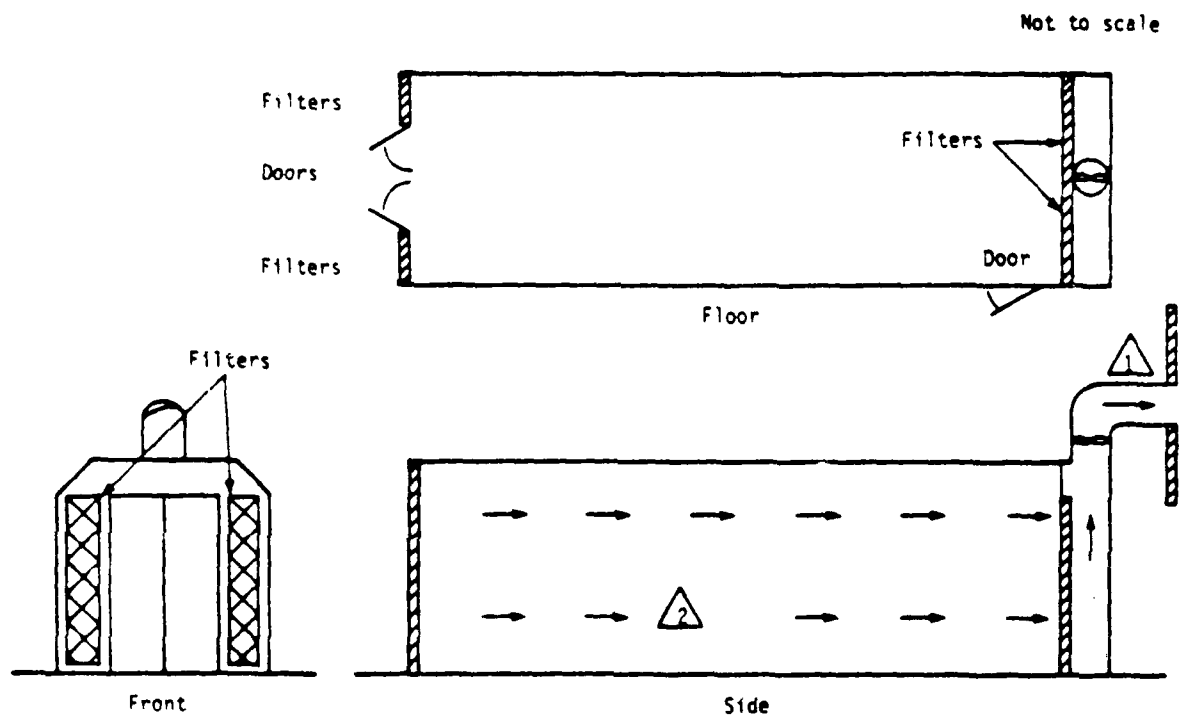


Figure 5. Schematic of Paint Spray Booth -- Travis Air Force Base, Building 1014.

1. Paint Processes and Usage

The paints used during the sampling period at Building 1014 were the same paints used at Building 550. It was, therefore, not necessary to take additional paint samples; rather the results obtained from the previous analyses were used.

The booth was not divided into sections because of its small size and the nature of the ventilation system. Records were kept of the amount of paint applied (the paint cans were weighed before and after use), as well as the time and rate it was consumed. These records are summarized in Tables 31 and 32. The particulate and organic sampling results discussed in subsequent sections are correlated with these records.

2. Flow Measurements

Daily anemometer readings were taken at the particulate filters along the back face of the booth. Rows of 1 foot by 1 foot square filter elements make up the four filter faces. Flow measurements were taken over each element, then integrated to obtain the total airflow through the booth. The results of the integrated flow calculations are presented in Table 33. The filter elements along the back face of the booth changed in color throughout the test, which indicated that they were clogging rapidly. Comparison between the anemometer data taken June 24, when the filters had just been replaced, and data taken June 30, at the close of the test illustrates the marked decrease (approximately 65 percent) in airflow through the filters.

There were no flow measurements taken using the EPA Method 2 procedure. Instead, results of the MM5 test procedure were used. The Method 2 procedure is part of the MM5 test, thus, volume flow measurements can be obtained from the MM5 results. Normally, when running MM5 sample tests, two traverses are done at 90 degrees to each other. Due to the precariously high and unstable location of the vertical sample port, it was decided that only horizontal traverses would be performed. The results of the volume flow measurements are given in Table 34. Note that the flow in the ducts decreased as a function of time. This is most likely because the particulate filters clogged.

Certain aspects of the ventilation system in Building 1014 cause the volume flow data to be suspect. A large fan is located immediately upstream of the sample port in the exhaust duct, and the duct itself is extremely curved. Both these attributes cause the flow in the duct to be nonlaminar. A more serious complication with the Building 1014 stack is that the outlet to the exhaust duct is flush with the building. Because of the outlet orientation, the duct is subject to large gusts of air flowing into the duct in the opposite direction to the exhaust flow. The MM5 train operators could feel these gusts when they opened the sample port to move the probe. All of these complications render the MM5 volume flow measurements unreliable.

TABLE 31. PAINT BOOTH OPERATING LOG -- TRAVIS AIR FORCE BASE,
BUILDING 1014

Date	Time	Paint time (min)	Comments
June 24	1415-1444	29	NI
June 29	1142-1147	5	1 operator
	1150-1156	6	1 operator
	1204-1209	5	1 operator
	1214-1219	5	1 operator
	1226-1231	5	1 operator
	1234-1236	2	1 operator
	1241-1247	6	1 operator
June 30	1007-1023	16	1 operator, plane gate
	1026-1044	18	1 operator, plane gate
	1306-1346	40	2 operators, plane gate
	1415-1446	31	2 operators, plane gate

TABLE 32. PAINT USAGE LOG -- TRAVIS AIR FORCE BASE, BUILDING 1014

Date	Time	Paint type	Amount used (kg)	Comments
June 24	1415-1444	Polyurethane Green	NI ^a	NI
June 29	1142-1147	Aircraft primer ^b	7.62	1 operator
	1150-1156	Aircraft primer	7.6	1 operator
	1204-1209	Aircraft primer	8.72	1 operator
	1214-1219	Aircraft primer	7.63	1 operator
	1226-1231	Aircraft primer	7.44	1 operator
	1234-1236	Aircraft primer	3.68	1 operator
	1241-1247	Polyurethane green	8	1 operator
June 30	1007-1044	Aircraft primer	4	1 operator
	1306-1346	Polyurethane green	10.9	2 operators
	1415-1446	Polyurethane green	8.5	2 operators

^aNo information.

^bSample taken at McClellan.

TABLE 33. VOLUMETRIC FLOWRATE ANEMOMETER DATA --
TRAVIS AIR FORCE BASE, BUILDING 1014

Site	June 24	June 30
Filter 1	3,390	1,220
Filter 2	3,420	970
Filter 3	3,100	1,115
Filter 4	3,320	1,205
Total (cfm)	13,230	4,510
Temperature (°F)	70	70
Barometric pressure (in. Hg)	28.3	28.8
Total (cfm @ STP)	12,447	4,318
Total (Lpm @ STP)	352,250	122,199

TABLE 34. VOLUMETRIC FLOWRATE EPA MM5 RESULTS --
TRAVIS AIR FORCE BASE, BUILDING 1014

Date	Volume flow		
	June 29	June 30	June 30
cfm @ STP:	16787	15835	14437
Lpm @ STP:	475072	448131	408567

The large discrepancy which exists between the anemometer data and the MM5 volume flow measurements can be partially explained by the fact that considerable leakage occurred around the filter elements in the booth. Small cracks (1/4 to 1/2 inches wide) were observed between the filter element edge and the frame holding the element. As the filter became clogged, the airflow through these cracks increased, which, in turn, caused the flow through the filters to decrease.

3. QC Measurements

The results of the organic module analysis of the MM5 tests are presented in Table 35. During the Test 1 interval, 29 minutes of painting occurred in the booth, thus, large concentrations of organics were detected. Tests 3 and 4 were also done during long painting intervals. Although some organics were detected, the concentrations detected were considerably lower than expected.

The results of the EPA Method 25A and BAAQMD Method ST-7 sampling trains are shown in Tables 36 and 37. The results of mass balance calculations, based on the ST-7 and NIOSH 1300 speciation data and the paint usage log, are also presented in Table 37. Agreement between the amount of paint used during the sampling interval and the amount of hydrocarbons detected by the ST-7 sampling train is within 70 percent.

During the sample time interval 1310 to 1355, large quantities of paint were consumed; correspondingly, high VOC concentrations were detected in the stack. The peak concentration found was 1,150 ppm, after subtracting the background CO₂. The piece that was painted at this time did not have a solid surface; thus, overspray was significant. These high concentrations were due to the fact that most of the paint consumed during this time interval did not adhere to the piece being painted. Therefore, a greater volume of paint per unit area is required for large pieces having small surface areas than for large pieces having large surface areas. During the sample interval immediately following, no painting took place and the piece was left to dry. At this time, the VOC concentrations were comparatively quite low (the peak VOC concentration found was 50 ppm after subtracting the CO₂ background). Because the total surface area of the piece was small, relatively few hydrocarbons were emitted while the piece dried.

The sampling intervals and volumes used in the NIOSH 1300 tests are presented in Table 38, along with the results of speciation analyses done on each charcoal tube. The hydrocarbon species data were used in the mass balance calculations described in the previous section.

Tube 905471 was placed in the spray booth while paint was being applied, however the quantity of paint consumed was not recorded. Tubes 905470, 905473, and 905474 were also sampling in the booth while large quantities of paint were being applied. It is not known why little or no VOCs were collected by these filters.

TABLE 35. MM5 ORGANICS SAMPLING RESULTS -- TRAVIS AIR FORCE BASE,
BUILDING 1014

	Test 1	Test 2	Test 3	Blank
Date	June 29	June 30	June 30	
Time	1150-1250	1008-1108	1310-1410	
Site	Stack	Stack	Stack	
Volume sampled (cf @ STP)	29.2	25.5	23.0	
Volume sampled (L @ STP)	826	722	653	
Semivolatile compounds detected (µg/sample)				
Phenol	109	29	6	0
1,3-Dichlorobenzene	4	0	0	0
1,2-Dichlorobenzene	5	0	0	0
Naphthalene	15	8	7	4
Diethylphthalate	4	0	8	1
n-Nitrosodiphenylamine	7	8	10	8
Di-n-butylphthalate	4	0	0	0
Butylbenzylphthalate	6	3	1	1
bis(2-Ethylhexyl)phthalate	14	21	98	0

TABLE 36. METHOD 25A RESULTS -- TRAVIS AIR FORCE BASE, BUILDING 1014

Day	Site	Time interval	Sample time (min)	Paint time (min)	Peak (ppm ^a)	Background organic carbon (ppm)	Approximate average (ppm ^b)	Integrated total (ppm ^b min)
June 30	Stack	1005-1020	15	13	16.5	3	12	120.6
		1020-1035	15	12	27	3	12	195
		1035-1050	15	9	28.5	3	18	225
		1310-1325	15	15	399	3	207	3,069
		^c 1325-1340	13	15	399	3	237	3,384
		^d 1340-1355	3	6	115.5	3	112.7	171
		1415-1430	15	15	237	12	123	1,809
		1430-1445	15	15	360	12	228	4,494
		1445-1500	15	1	360	12	153	2,847

^appm refers to carbon.

^bppm refers to carbon concentration minus the background levels.

^cInstrument off scale due to high concentrations; did not record for 2 minutes.

^dSample time short due to zeroing of instrument during sample time interval.

TABLE 37. METHOD ST-7 RESULTS -- TRAVIS AIR FORCE BASE, BUILDING 1014

Day	Site	Time interval	Sample time (min)	Paint time (min)	Peak (ppm) ^a	Background CO ₂ (ppm)	Approximate average (ppm) ^b	Integrated total (ppm min) ^b	Air flow rate (Lpm)	Mass of carbon (kg)	Amount of paint used (kg)	Approximate mass of carbon in stack (kg)
June 30	Stack	1005-1020	15	13	400	350	25	460	448,130	0.11		
		1020-1035	15	12	425	350	25	440	448,130	0.106		
		1035-1050	15	9	400	350	25	420	448,130	0.101		
									Total:	0.317	4	1.31
	c	1310-1325	15	15	1450	350	500	8,180	408,500	1.8		
		1325-1340	15	15	1350	350	525	7,400	408,500	1.63		
		1340-1355	15	6	1500	350	400	4,800	408,500	1.06		
			8	0	400	350	25	260	408,500	0.057		
									Total:	4.547	10.9	4.01
	d	1420-1430	15	15	975	375	375	3,700	408,500	0.81		
		1430-1445	7	15	1275	375	525	3,440	408,500	0.76		
		1445-1500	15	1	1350	375	175	3,160		0.7	8.5	3.12
									Total:	2.27		

^appm refers to carbon.^bppm refers to carbon concentration minus the background values.^cSample time shortened due to 2-minute bypass of instrument during sample interval.^dSample time short due to 8-minute bypass of instrument during sample time interval.

TABLE 38. NIOSH 1300 RESULTS -- TRAVIS AIR FORCE BASE, BUILDING 1014

Charcoal tube number	Date	Time	Site	Volume sampled (L @ STP)	VOC's detected (mg) ^a
905471	June 29	1445-1511	Booth	2.76	0.052 Butyl acetate 0.16 o-Xylene 0.085 m-Xylene 0.015 p-Xylene 0.112 4-Methyl-2-pentanone
905474	June 30	1002-1050	Booth	2.67	0.001 o-Xylene
905470	June 30	1003-1031	Booth	2.89	ND
905473	June 30	1040-1130	Booth	4.85	ND
905480	June 30	1309-1339	Stack	2.97	0.112 Butyl acetate 0.189 o-Xylene 0.044 m-Xylene 0.019 p-Xylene 0.123 4-Methyl-2-pentanone
905469	June 30	1342-1414	Stack	2.75	0.006 Butyl acetate 0.029 o-Xylene 0.002 m-Xylene 0.001 p-Xylene 0.004 4-Methyl-2-pentanone

^aDetection limit is 0.5×10^{-3} mg/tube.^bUnknown peak at 13.0 minutes.

Tube 905469 was placed in the stack while large quantities of paint were consumed, which explains the large concentrations detected in the filter. Only 2 minutes of painting were done during the time that Tube 905480 was in the stack. It was expected that little or no VOCs would be detected, and none were.

4. Particulate Concentration Measurements

The particulate data garnered from the MM5 sampling train are presented in Table 39. The particulate concentrations detected in the stack were high. It is interesting to note that the particulate levels increase as a function of time. This would indicate that, as the filters become clogged, the flow through the cracks around the filter elements increased, which, in turn, caused an increase in the stack particulate concentration.

The volume sampled and mass of particulate collected in the NIOSH 500 tests are listed in Table 40. It is clear that significant quantities of particulate were present inside the paint booth while paint was being applied. During the time interval in which Filters 1 and 42 were collecting particulate, 29 minutes of painting occurred. Filters 17 and 25 were sampling during a 34-minute painting period. In each case, it was expected that large quantities of particulate would be collected.

In summary, at the Travis Air Force Base paint facility in Building 1014, VOC concentrations were found as high as 1,500 ppm (see Table 37). Particulate concentrations were found to be 16 mg/m³ inside the booth (see Table 27). The peak estimated VOC emission concentration was 58.3 mg/m³ (see Table 37).

TABLE 39. MM5 PARTICULATE SAMPLING RESULTS -- TRAVIS AIR FORCE BASE
BUILDING 1014

Date	Time	Sample site	Stack gas moisture (percent)	Stack gas temperature (°F)	Sample volume (cf @ STP)	Volumetric flowrate (scfm)	Particulate weight (±0.0005 g)	Particulate concentration (mg/scf)	Particulate emission rate (g/m)
June 29	1150-1250	Exhaust vent	2.2	74	29.16	16,787	0.0037	4.48	2.13
June 30	1008-1108	Exhaust vent	2.3	71	25.47	15,835	0.0041	5.69	2.55
June 30	1310-1410	Exhaust vent	2	75	23.03	14,437	0.0054	6.29	3.39

TABLE 40. NIOSH 500 RESULTS -- TRAVIS AIR FORCE BASE, BUILDING 1014

Filter number	Date	Time	Site	Volume sampled (L @ STP)	Particulate on filter (mg)	Mass (mg) particulate per m ³
1	June 24	1414-1542	Inside	128.96	0.06	0.47
42		1415-1544	Inside	116.9	0.48	4.1
17	June 29	1142-1252	Inside	95.09	0.9	9.5
25		1142-1252	Inside	98.41	1.45	14.7

SECTION III

CONTROL CONCEPTS

The three general approaches to controlling VOC emissions from painting facilities are:

- Process and equipment change
- Reformulation
- Add-on devices

Each of these methods are discussed in detail in the following paragraphs.

A. PROCESS AND EQUIPMENT CHANGE

This method entails altering the paint application process. At the McClellan spray booth, paint was applied with an air-assisted airless spray technique, in which the paint was forced through a small orifice at high pressure and atomized as it leaves the spray gun. At Travis, the paint was applied with air-atomized, conventional spray equipment. For this process, compressed air is used as the atomizing agent for the paint spray.

Alternate paint application techniques are available on the market; the most promising being the electrostatic spray method. In this process, paint particles are charged to a high potential as they pass through an electrode. The surface to be coated is grounded so that it is at a low potential compared to the paint particles. Attraction between the electrically charged paint particles and the surface causes the paint to be drawn to the surface, thus reducing overspray. One drawback to the electrostatic spray coating method is that paints with a high conductivity cannot be applied because the paint particles do not become highly charged. Furthermore, if an electrostatic spray system is installed, certain precautions must be taken to preclude an explosion hazard (6). With adequate safety rules, proper equipment, and safeguards, this should not be a problem (4).

The principal factor used to compare paint application technologies is the transfer efficiency of the device. The transfer efficiency is determined by the environment, the paint, the piece being painted, worker ability, and equipment condition. Results of comparison studies done on the range of transfer efficiencies of air atomized, airless, and electrostatic spray techniques are presented in Table 41. Identical tests were performed on three target types: flat plate, vertical cylinder, and a miscellaneous flat target. From the results, it is clear that the transfer efficiency is strongly dependent on target type (6).

These results indicate that, given identical operating conditions, the electrostatic spray technique is consistently the most efficient of the three paint application methods. The airless spray technique is slightly more

TABLE 41. COMPARISON OF TRANSFER EFFICIENCIES FOR THREE
PAINT APPLICATION TECHNIQUES USING THREE
DIFFERENT TARGETS

Target type	Application technique		
	Air atomized	Airless	Electrostatic
<u>Flatplate Target</u>			
Mean	68.3	72.3	90.3
Range	57.1 to 85.9	63.1 to 80.5	83.8 to 96.1
<u>Vertical Cylinder Target</u>			
Mean	12.6	12.1	61.9
Range	9.5 to 16.5	10.4 to 14.8	42.2 to 80.8
<u>Miscellaneous Flat Target</u>			
Mean	31.4	30.9	71.1
Range	25 to 41.7	25.9 to 35	58 to 83.6

efficient than the air spray method for a flat plate target, otherwise they are virtually identical.

A product literature survey was done to compare the transfer efficiency ranges of other paint application techniques available. These spray devices, along with the approximate transfer efficiency ranges associated with them, are listed in Table 42.

Another possible equipment change is to modify the spray booth in such a way as to make VOC reduction devices more easily adopted. The most promising modification is the recirculation of a large portion of the exhaust air back into the spray booth. This modification, called recirculation, allows a reduction in the volume flow which requires processing. Recirculation is discussed in detail in Section 4.

B. REFORMULATION

The reformulation option entails changing the paints and solvents that are used. In general, low-solvent coatings with a high solids content or waterborne coatings are substituted for high-solvent coatings. This option is possible, but not very likely because of the great variety of paints and coatings used by the Air Force. Changing the paint composition would also require changing the military specifications for coatings used in the facilities included in this report.

C. ADD-ON DEVICES

Because of their effectiveness, these are perhaps the most promising options for the paint spray booth facilities at Travis and McClellan Air Force Bases. There are two types of add-on devices available: collection devices and destruction devices.

1. Collection Devices

This type of control device is generally used if the market value of the collected solvents is high. There are two types of collection devices:

- Carbon adsorption is a process in which the solvent-laden air is passed through a carbon filter cartridge where the solvents are collected by adsorption on the charcoal. The solvents are retrieved by heating the cartridge to vaporize the solvents, which are then collected in a condenser.
- Condensation is a process whereby the solvent-laden air is cooled, and the solvents are condensed out of the flow. A recent advancement in this technology is the development of a turbine expansion process which cools a solvent/air mixture. Research by the Department of Energy (DOE) is underway to evaluate this technology.

TABLE 42. PAINT SPRAY TECHNOLOGIES AND ASSOCIATED
TRANSFER EFFICIENCIES FOR A MISCELLANEOUS
FLAT TARGET

Spray device	Transfer efficiency Range (%)
Air assisted airless	25 to 45
Electrostatic air	45 to 75
Electrostatic air-assisted airless	55 to 85

The most viable of these methods is the carbon adsorption process because it requires minimal equipment change, as well as comparatively little energy.

2. Destruction Devices

The two most common methods of solvent destruction both involve incineration. They are:

- Thermal incineration, in which the solvent-laden air must be heated to approximately 1,400°F to ensure 90 to 98 percent destruction.⁶
- Catalytic incineration, in which the solvent laden air must be heated to 1,000°F for the same level of destruction (6).

If the market value of the recovered solvents is low (as is the case for the Air Force paint spray booths), it may be more economical to incinerate the exhaust solvents contained in the air than to collect them (6).

SECTION IV

RECIRCULATION MODIFICATIONS

A. BACKGROUND AND PURPOSE

Based on the control concepts discussed in Section 3, it is obvious that a combination of control options may be required. Thus, the use of recirculation in conjunction with add-on control systems may be the most viable and economical approach to controlling VOC emissions from paint spray booths. The emission characterization tests conducted in this program were intended to provide baseline data for the design of recirculation modifications to applicable spraybooths. The modifications, coupled with an add-on control system, represent a potentially viable and economical VOC emission control concept.

The removal efficiency of a VOC control device in terms of energy used, as well as percent of solvents collected or destroyed, is a function of several variables, such as:

- Solvent concentrations
- Flowrates
- Temperatures
- Solvent composition
- Mechanical efficiency of the specific VOC control technology (i.e., condensation versus incineration)

Although these variables are not mutually independent, they must be optimized to create an efficient and safe control system.

A cost-effective way to remove solvents from air flowing through a paint spray booth is to decrease the amount of air which requires processing and, simultaneously, increase the solvent concentration in the air. This is best accomplished by recirculating the exhaust air back into the spray booth. To maintain the VOC concentration well below safety limits, a portion of the recirculating air is bled off and routed to an add-on VOC removal device (i.e., carbon adsorption bed, incinerator, etc.). The air which is bled off is replaced with external makeup air. This process, called recirculation, greatly reduces the quantity of air which requires processing, which in turn reduces the size and number of add-on VOC control devices and greatly improves removal economics. There is a possibility that the recirculation system designs presented in this section may already be patented (7). In this case, permission from the patent holder may be required before the recirculation systems can be installed.

This section describes general issues which must be considered in designing a recirculation system. In addition, site-specific issues are addressed which pertain to each of the paint spray facilities included in this study.

B. DESIGN CONSIDERATIONS

The salient points to be considered in developing a recirculation system are:

- Federal, state and local safety standards must be met.
- Product quality must not be affected.

1. Safety Standards

The safety standards which must be considered are put forth by the National Fire Protection Association (NFPA) and the Occupational Safety and Health Administration (OSHA). To eliminate the possibility of fire and explosions in painting operations, NFPA regulations suggest and OSHA requires that sufficient ventilation air be present to dilute the airborne solvents to a concentration below 25 percent of the Lower Explosive Limit (LEL) (6). The LEL is the solvent concentration below which a mixture of air and solvents will not sustain combustion. A list of common paint solvents with the corresponding LEL values is given in Table 43.

To prevent dangerous exposure to high concentrations of hazardous compounds, OSHA requires that workers not be exposed to solvent concentrations in excess of the threshold limit value (TLV). This value is the maximum concentration at which no adverse health effects will be experienced by workers. In general, TLV concentrations are much lower than 25 percent of the LEL (8). However, if full protection is provided for the worker (i.e., sealed suits and an air-supplied respirator), the TLV requirement is not an issue, and the solvent concentration can be increased to 25 percent of the LEL (9).

Because the spray booths included in this study are under the jurisdiction of the Department of Defense, the safety standards with which they must comply are defined by Federal OSHA requirements. Paint booth facilities operated by private interests must comply with state and local safety requirements which are generally more stringent than Federal OSHA requirements. For example, the California OSHA does not allow recirculation in paint spray booths. Before designing paint spray booth modifications, the applicable safety and health requirements should be investigated.

2. Product Quality

The increase of VOC concentrations in the spray booth may have an impact on the product quality in a number of ways. If several paint colors are used continuously, the piece which is painted last may have a color pattern different from what the operator desires. This can be minimized by efficiently filtering the air before it is recirculated back into the booth. This has not been a problem at other large-scale recirculation projects (10).

The increase in solvent concentrations in the air as a result of recirculation may cause an increase in the time required to dry a freshly painted piece. The solvent emission rate from a painted surface (i.e. the

TABLE 43. COMMON PAINT SOLVENTS WITH CORRESPONDING
VALUES FOR 25 PERCENT LEL

Solvent	25 percent of of the LEL (percent by volume)
Acetone	0.65
Ethanol	1.075
Isopropyl alcohol	0.5
MEK	0.45
Toluene	0.35
Xylene	0.25
2 Butoxy ethanol	0.35
Butyl acetate	0.35
4-Methyl-2-pentanone	0.34

drying rate) is driven by the solvent diffusion gradient. Lowering the gradient (by increasing the solvent concentration in the drying air) may decrease the drying rate. However, this should not be a problem because the VOC concentration in the booth will always be well below the saturation level.

C. PROPOSED RECIRCULATION MODIFICATION; MCCLELLAN AIR FORCE BASE --
BUILDING 655

The spray booth ventilation system at Building 655 is complex, and installing a recirculation system will require rerouting of the duct work. A schematic diagram of a conceptual recirculation design is given in Figure 6. For the sake of comparison, a schematic of the booth as it now stands is given in Figure 6. The key consideration in designing a recirculation system is balancing the pressure drops across the ducts and filters. Calculations described in Section IV.E were used to determine the bleed-off rate required to maintain the VOC concentrations in the booth well below the 25 percent LEL. Allowing for a safety factor of 2, it was determined that the minimum required flowrate is 1,500 cfm at STP.

In this recirculation system design, the exhaust ducts from the sumps are rerouted so that Ducts 1, 2, 5, and 6 exhaust to a chamber at one end of the booth, and Ducts 3, 4, 7, and 8 exhaust to a chamber situated at the opposite end. Bleed ducts leading from each of these chambers are connected

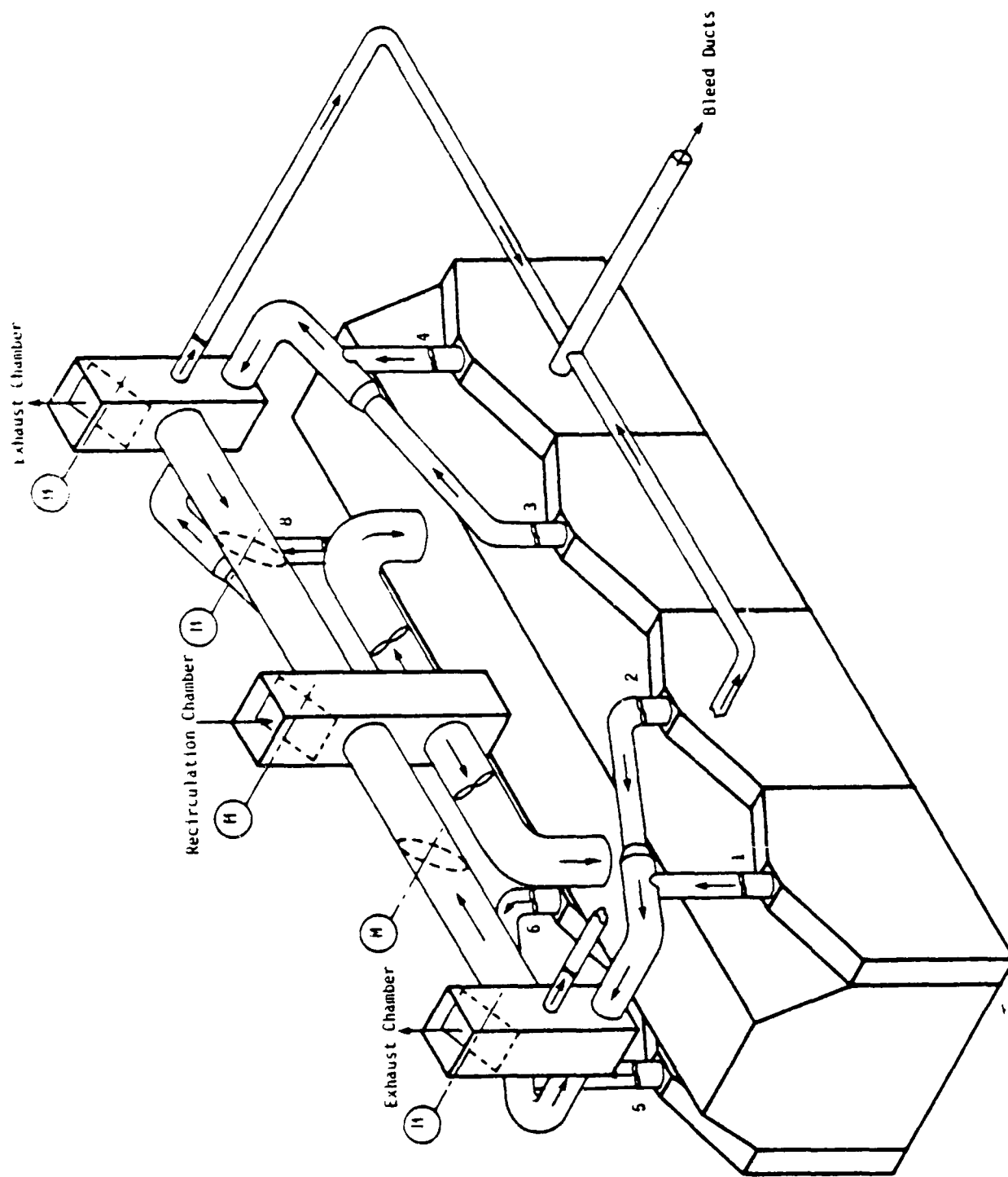


Figure 6. Schematic of Recirculation System -- McClellan Air Force Base.

together and routed to the VOC control device, which will probably be located outside of the building. Most of the air in the exhaust chamber passes to the recirculation chamber, where it mixes with fresh air ducted in from the outside and is reintroduced into the spray booth.

Because the VOC concentration in the booth is a function of where in the booth paint is applied, it is possible to have a high VOC level at one end of the booth, and a much lower level at the other end. For this reason, it was decided that an LEL monitor should be placed in each of the exhaust chambers.

The amount of in-leakage which occurs around the doors of the spray booth should be minimized for two reasons. The air which leaks in is not filtered, thus, it carries particulate and contaminants into the booth. The second reason is that the air which leaks in is not mixed with the recirculated air. This may cause localized high VOC concentrations which are potentially hazardous. The makeup air which enters the booth should come primarily through the external makeup air duct and be mixed thoroughly with the recirculated air before being filtered and vented into the spray booth. The makeup air does not necessarily have to come from outside; the only requirement is that the source be external to the spray booth, away from stacks or vents. Not all the in-leakage can be eradicated, however, because a negative pressure must be maintained in the spray booth to prevent solvent laden air from escaping into the surrounding area.

The makeup air duct also serves to immediately flush the booth with outside air in the event that high VOC concentrations are detected by the LEL monitor. If this happens, dampers in the makeup air and exhaust ducts open, which returns the booth to a single-pass ventilation operation. When the high VOC concentration is sufficiently low, the ventilation system returns to normal operation.

It was estimated that materials and installation costs for the recirculation system illustrated in Figure 6 would be approximately \$60,470. This estimate does not include the investment and installation costs of the actual VOC emission control device (i.e., incinerator, carbon adsorption bed, etc.), nor does it include the cost of the LEL detector and damper control system. The estimate does include the cost of routing the bleed-flow out of Building 655 and down to the ground. A breakdown of the approximate costs is given in Table 44.

It should be noted that in the material cost estimation, it was assumed that several pieces of equipment currently in place could be used in the new design. The following is a list of the equipment which may be reused: two air supply fans, eight exhaust air fans, supply air diffusers, exhaust air grilles, supply air ductwork (if practical) and duct and fan support structures (if practical).

Installation and operating cost estimates have also been performed for both carbon adsorption and incineration VOC emission control systems. These are discussed in the following paragraphs. The relevant operating parameters

TABLE 44. COST TO CONSTRUCT RECIRCULATION SYSTEM -- McCLELLAN
AIR FORCE BASE, BUILDING 655

Quantity	Part description	Approximate cost
60 LF	60-in. sq. duct (galv. ST1)	\$142/LF = 8,520
90 LF	60-in. ϕ duct (galv. ST1)	\$95/LF = 8,550
40 LF	48-in. ϕ duct (galv. ST1)	\$47/LF = 1,880
80 LF	34-in. ϕ duct (galv. ST1)	\$35/LF = 2,800
50 LF	9-in. ϕ duct (galv. ST1)	\$5/LF = 250
80 LF	6-in. ϕ duct (galv. ST1)	\$4.5/LF = 360
4 EA	34-in. ϕ x 90° elbow (galv. ST1)	\$572/ea = 2,288
4 EA	48-in. ϕ x 90° elbow (galv. ST1)	\$858/ea = 3,432
2 EA	60-in. ϕ x 90° elbow (galv. ST1)	\$1,100/ea = 2,200
5 EA	60-in. motorized damper	\$900/ea = 4,500
2 EA	60-in. blowers	\$1,300/ea = 2,600
3 EA	60 in. sq bird and insert screen	\$900/ea = 2,700
1 EA	Vapor monitor	Not included
1 EA	Bleed process equipment	Not included
Total labor and material		\$40,000
Tax		\$ 1,600
General contractor markup		\$ 4,800
Total		\$46,480
Contingency		\$ 8,830
Engineering fees (excluding process equipment)		\$ 5,000
Two air-supplied sealed suits		\$ 160
Grand Total (excluding process equipment and monitor)		\$60,470

in determining installation and operating costs of carbon adsorption or incineration systems are the flow rate and the solvent concentration. For the McClellan facility, a bleed rate of 1,500 cfm is optimal. This will result in a VOC concentration ranging from 0 to 1,000 ppm.

Cost projections for an activated carbon adsorption system consider several issues. The carbon adsorption efficiency depends on the molecular weight and the polarity of the solvent, as well as the type of activated carbon. The adsorption efficiency of fresh carbon varies from 0.4 to 1.0 grams of solvent adsorbed per gram of carbon (11). Another consideration is that, after the first regeneration cycle, the carbon typically has less than one-half of the adsorption capacity of fresh carbon.

Regeneration of the saturated carbon may be accomplished in a number of ways. Onsite regeneration is possible with steam stripping or hot-air regeneration devices operated in conjunction with the carbon bed. The carbon may be hauled to an offsite regeneration facility, or it may be disposed of by landfill or incineration. The appropriate regeneration or disposal method is determined by economic considerations. This study determined that a steam-stripping unit would be the most viable option for carbon regeneration.

The total installed cost for a carbon adsorption, steam stripping unit is approximately \$80,000 to \$90,000. The bed will require regenerating every 2 to 3 days if the booth is operated 24 hours per day. Each regeneration cycle will produce 250 to 300 gallons of water containing 10 percent solvents (11). If this wastewater can be treated onsite, the daily operation costs may be low. If, however, the wastewater must be disposed of, costs of \$1,130 to \$1,590 may be incurred per regeneration cycle.

The total installed cost for an incineration system equipped with a primary heat recovery unit is approximately \$40,000 to \$50,000. If the incoming air is preheated to 600°F the natural gas requirement will range from 18.9 to 25 scfm, depending on the influent solvent concentration (11). For a natural gas cost of \$4 per 1,000 scf, this translates to \$100 to \$144/day.

For process air containing solvent concentrations between 1,000 ppm and 25 percent of the LEL, an incineration system which takes advantage of the fuel value of the solvent in the air is probably more economical than a carbon adsorption system (6).

D. TRAVIS AIR FORCE BASE -- BUILDING 550

Because of the complexity of the ventilation system at Building 550, it was decided to develop a list of issues and concerns which must be addressed before designing a recirculation system.

The first issue of concern is to determine peak paint usage rates in the spray booth so that a minimum bleed-off rate can be determined. The maximum paint usage rate at the 550 spray booth was 3.97 kg in 23 minutes, which

translates to approximately 10 kg per hour. Another consideration is the fact that the paint used at spray booth facilities is composed of many solvents, thus, it must be decided which LEL value should be used in determining maximum allowable VOC concentrations in the booth. If the LEL of a particular solvent of interest is considerably smaller than the LEL values of any other solvents, it is likely that the lowest LEL value will be used.

A complication unique to the Building 550 facility is that significant in-leakage occurs behind the particulate filters at the junction with the exhaust ducts. During the test sequence, it was noted that, as the filters became clogged with particulate, the in-leakage increased (see Section II B2). In a recirculation system, this in-leakage would dilute the recirculated air, which would defeat the purpose of the recirculation system. A recirculation system design for this facility would have to eliminate this in-leakage problem.

F. TRAVIS AIR FORCE BASE -- BUILDING 1014

Building 1014 has been selected as a possible site for the installation of a pilot recirculation system. This spray booth was selected primarily because of the simple ventilation system associated with it. Another reason is that, because the booth is used seasonally for 8 hours a day, no major painting operations would be interrupted during construction. The following sections describe how various health, safety and design issues have been addressed in developing a conceptual design of a recirculation system for the paint spray facility at Building 1014.

1. Peak Hydrocarbon Concentrations

During the painting interval which resulted in the highest VOC concentrations in the stack, the paint consumption rate was 16.35 kg per hour. The paint used at this time, polyurethane green, has a percent volatile concentration by weight of 53.6 percent (see Table 20) which implies that 53.6 percent by weight of the paint is organic solvent. Thus, at the paint usage rate of interest, 8.8 kg of solvents was consumed per hour. A worst-case scenario would be to assume that this high paint usage rate would continue for 4 hours. This would result in the emission of 35.2 Kg of solvent.

2. Maximum Allowable Solvent Concentration

The first issue to be considered is the composition of the emitted solvent. According to the results of the GC/MS analysis (Table 19), the paint solvent is composed of 66 percent MEK, 10 percent xylenes, 9.5 percent cyclohexanone, 8.4 percent 4-methyl-2-pentanone and at least 6 percent butyl acetate. The uncertainty in the butyl acetate concentration stems from the fact that a lower bound only was given for this compound in Table 19, which implies that the actual concentration of butyl acetate may be considerably higher (up to ten times higher). The fact that the polyurethane green paint has two components which are mixed in a 1:1 volume ratio was considered.

The paint booth measures 60 feet long, 18 feet high, and 18 feet wide. The volume of the booth is, therefore 19,440 ft³ (550 m³). With no ventilation system in the booth, at the consumption rate of 8.8 kg/hr, the solvent concentration after 4 hours would be 63 g/m³. The concentration in ppm of a specific compound depends on the molecular weight of the compound. The following analysis assumes that the solvent is composed solely of one compound (i.e., all MEK or xylenes or butyl acetate, etc.). The resultant ppm concentration of the compound in the booth is compared to the 25 percent LEL value for that particular compound. The compound which has the largest factor difference will be used to determine the maximum recirculation which will be allowed. Equation (1) illustrates how the values presented in Table 45 were achieved.

3. Xylene

Molecular Weight: 106.16 grams/mole

25 percent of LEL: 0.25 percent by volume = 2,500 ppm xylene

$$\frac{63 \text{ g Xylene}}{\text{m}^3 \text{ of air}} \times \frac{1 \text{ mole Xylene}}{106 \text{ g Xylene}} \times \frac{22.4 \text{ L}}{\text{mole}} \times \frac{1 \text{ m}^3}{1,000 \text{ L}} = \frac{0.0133 \text{ m}^3 \text{ Xylene}}{\text{m}^3 \text{ air}} \quad (1)$$

$$= 13,300 \text{ ppm Xylene}$$

Thus, if the solvent were composed solely of xylene, the xylene concentration in the booth after 4 hours would be 6.5 times higher than recommended by the NFPA.

The calculated values in Table 45 indicate that the xylene concentration should be used as the design criterion for a recirculation system at Building 1014.

4. Minimum Required Bleedoff Rate

To determine the minimum flow rate required to prevent the buildup of significant concentrations of solvents, it is necessary to formulate the solvent concentration in the booth as a function of time. For the following analysis, the rate at which the solvent is released into the booth is known, the bleed rate is considered constant, and the initial concentration of solvent in the booth is zero. Standard conditions are assumed in the following analysis:

TABLE 45. SOLVENT CONCENTRATIONS IN PAINT SPRAY BOOTH -- TRAVIS AIR
FORCE BASE, BUILDING 1014

Compound	Concentration (grams/m ³)	Molecular weight (grams/mole)	Resultant concentration (ppm)	25 percent LEL (ppm)	Approximate difference factor
Xylene	63	106	13,300	2,500	6.5
4 methyl- 2-pentanone	63	100.16	14,000	3,400	4
Butyl acetate	63	116	12,200	3,500	3.4
MEK	63	72.1	19,450	4,500	5

Let:

$M(t)$ = Total mass of solvent in the booth (Kg/hr).

\dot{M}_p = Rate at which the solvent is emitted into the booth.

= 8.7 Kg/hr.

\bar{V}_{out} = Volume flow which is bled off from the booth (m^3/min).

= Constant

V_{booth} = Booth volume.

= ($550 m^3$)

$X(t)$ = Rate at which solvents are removed from the booth.

= Kg/hr

$$= \frac{\bar{V}_{out}}{V_{booth}} n(t)$$

$M(t=0)$ = Boundary condition which specifies the initial solvent concentration in the booth.

= 0

The results of a mass balance evaluation of the booth yields the following equation:

$$\frac{dM(t)}{dt} = \dot{M}_p - X(t) \quad (2)$$

This expression implies that the rate at which the solvent concentration increases in the booth is equal to the rate at which solvents are emitted into the booth minus the rate at which the solvents are removed from the booth. The expression may be simplified:

$$\frac{dM(t)}{dt} = \dot{M}_p - \frac{\bar{V}_{out}}{V_{booth}} M(t) \quad (3)$$

The solution to this linear nonhomogeneous first-order differential equation may be calculated by a change of variables, or may be found in any mathematical handbook containing tables of solutions to differential equations.¹² The solution to Equation (3) is:

$$M(t) = \dot{M}_p \frac{V_{\text{booth}}}{V_{\text{out}}} \left(1 - \exp \left(- \frac{V_{\text{out}}}{V_{\text{booth}}} (t) \right) \right) \quad (4)$$

What remains is to determine what the flowrate should be so that, after 4 hours, the solvent concentration is less than 25 percent of the LEL for xylene. The minimum required flow rate can be calculated by equating the solvent concentration in the booth ($M(t)$) with the 25 percent LEL value for xylene (2,500 ppm), and inserting the known values for V_{booth} and \dot{M}_p .

$$t = 4 \text{ hours}$$

$$M(t=4) = 2,500 \text{ ppm in the booth}$$

$$= 6.5 \text{ kg}$$

$$\dot{M}_p = 8.7 \text{ kg/hr}$$

$$6.5 \text{ kg} = \frac{8.7 \text{ kg}}{\text{hr}} \frac{550 \text{ m}^3}{V_{\text{out}}} \left(1 - \exp \left(- \frac{V_{\text{out}}}{550 \text{ m}^3} (4 \text{ hrs}) \right) \right) \quad (5)$$

The solution to this equation can be found iteratively. The minimum flow rate required in the bleed off system is 12.2 m³/min @ STP (430 scfm) which represents 2.2 percent of the total volume of the booth. For a safety factor of 2, the flow rate for the bleed off system will be 24.4 m³/min @ STP (860 scfm).

A similar calculation was carried out, using the 25 percent TLV for xylene in place of the 25 percent LEL value. Based on this calculation, it was determined that under current operating conditions, the 25 percent TLV is exceeded. It was found that the current flow rate (approximately 15,000 cfm @ STP) would have to be increased by a factor of three to lower the solvent concentrations below the 25 percent TLV.

5. Conceptual Design

A schematic diagram of the recirculation system for Building 1014 is given in Figure 7. In this design, the exhaust duct is rerouted so that it passes over the roof and down to the front of the spray booth. The filters

in the booth doors are removed and the doors sealed so that little outside air will pass through. The fan currently in the exhaust duct is used as the exhaust fan. In addition, an intake fan is installed at the front of the booth. Particulate filters are placed at the front face of the booth. To ensure that the VOC concentrations in the booth remain below safety levels, an LEL monitor is placed in the recirculation duct downstream of the exhaust fan.

A bleed-off duct leading to a VOC removal device is connected to the recirculation duct on the roof of the spray booth. If an incinerator is selected as the control device, the bleed duct will be routed outside to a small shed in which the incinerator will be housed. If a collection device is utilized, the duct will be routed to the ground where a removable filter, condenser or charcoal bed will be located.

At the front of the booth, a fresh air duct is connected to the recirculation duct upstream of the intake fan. The purpose of this duct is to supply fresh air to replace the air removed in the bleed-off duct. A damper located inside the duct will be opened completely if the VOC concentration in the booth reaches a dangerous level. Large quantities of fresh air will flow through the booth and dilute the high VOC concentrations.

It was estimated that materials and installation costs for the recirculation system illustrated in Figure 7 would be approximately \$32,882. This estimate does not include the investment and installation costs of the actual control device (i.e., incinerator, carbon absorption bed) nor does it include the LEL detector and damper control system. The estimate does include the cost of routing the bleed flow from the hangar to the ground. A breakdown of the approximate costs is given in Table 46.

The relevant operating parameters in determining installation and operating costs of carbon adsorption or incineration systems are the flow rate and the solvent concentration. For the Travis 1014 facility, a bleed rate of 860 cfm is optimal. This will result in a VOC concentration of 0 to 1,000 ppm.

The total installed cost for an incineration system equipped with a primary heat recovery unit is approximately \$40,000 to \$50,000. If the incoming air is preheated to 600°F, the natural gas requirement will range from 12.6 to 17.4 scfm, depending on the influent solvent concentration [11]. For a natural gas cost of \$4 per 1,000 SCF, this usage rate translates to \$24 to \$33/day.

The total installed cost for a carbon adsorption, steam-stripping unit is approximately \$40,000 to \$50,000. The bed will require regenerating every 6 to 9 days. Each regeneration cycle will produce 250 to 300 gallons of water containing 10 percent solvents. If this wastewater can be treated on site, the daily operating costs may be low. If, however, the wastewater must be disposed of, costs of \$1,130 to \$1,590 may be incurred per regeneration cycle. An additional expense which may be required at this facility is a

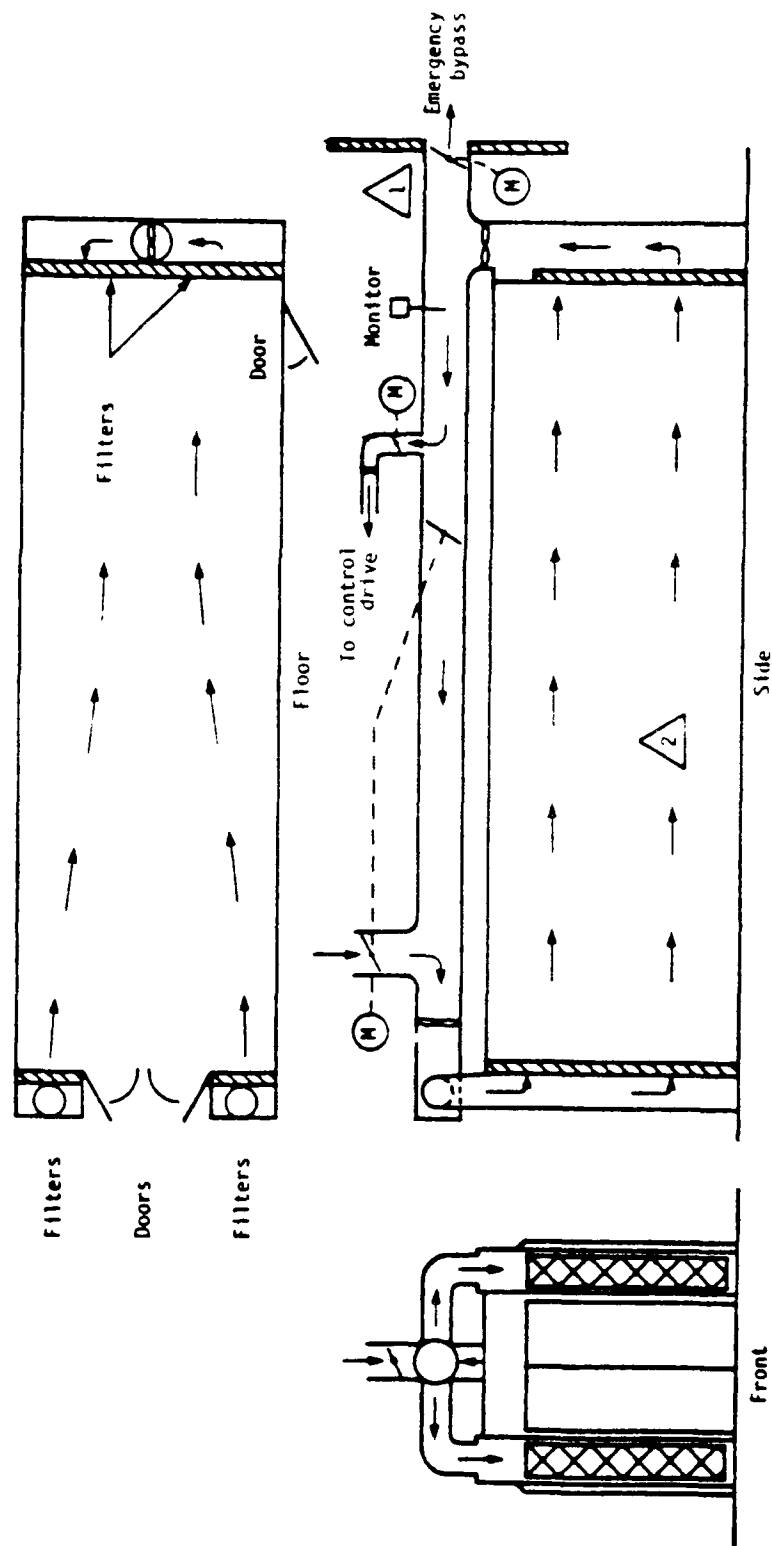


Figure 7. Schematic of Recirculation System -- Travis Air Force Base, Building 1014.

TABLE 46. COST TO CONSTRUCT RECIRCULATION SYSTEM -- TRAVIS AIR
FORCE BASE, BUILDING 1014

Quantity	Part description	Approximate cost
90 LF	46-in. ϕ duct (galv. stl)	\$47/LF = 4,230
18 LF	36-in. ϕ duct (galv. stl)	\$35/LF = 630
50 LF	6-in. ϕ duct (galv. stl)	\$4.5/LF = 225
36 LF	36-in. x 48" duct (galv. stl)	860# @ \$4.05/# = 3,483
2 EA	46-in. x 46" x 46" tee (galv. stl)	\$600/ea = 1,200
2 EA	36-in. x 90° elbow (galv. stl)	\$572/ea = 1,144
1 EA	46-in. motorized damper	700
1 EA	Dual linked 46" motorized damper	1,200
1 EA	6-in. motorized damper	200
1 EA	46-in. ϕ in-line fan (15900 CFM)	4,000
1 EA	6-in. ϕ motorized damper	1,300
1 EA	46-in. ϕ end cap	200
1 EA	46-in. ϕ insect and bird screen	850
1 EA	Vapor monitor and mounting	Not included
1 EA	Bleed process equipment	Not included
Total labor and material		\$19,362
Tax		\$875
General contractor markup		\$3,000
Total		\$23,237
Contingency		\$4,485
Engineering fees (excluding process equipment)		\$5,000
Two air-supplied seal suits		\$160
Grand total (Excluding process equipment and monitor)		\$32,882

steam-generating unit such as an electric boiler. The installation cost for such a device may range from \$5,000 to \$10,000.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. General

VOC emissions from the three spray paint booths included in this study exceeded allowable limits. The emissions from these facilities can be significantly reduced with a variety of add-on control devices, possibly coupled with a recirculation system.

2. McClellan Air Force Base

The Sacramento County Air Pollution Control District (SCAPCD) requires that less than 420 grams of nonexempt VOC be present per liter of paint used for camouflaging purposes (13). According to the data presented in Table 3, one type of paint used at McClellan contains up to 67.6 percent volatile organics by weight. When the density is factored in, it is estimated that this paint contains approximately 750 grams of VOC per liter. Table 2, shows that this particular paint does not contain any of the exempt organic compounds allowed by rule 451 of the SCAPCD. Thus, the 750 grams of VOC measured per liter of paint is in the nonexempt category. The test results from this facility accounted for 44 to 48 percent of the total VOC emissions expected. Despite recent efforts to reduce VOC emissions, the paint booth included in this study is out of compliance due to the usage of paint containing large quantities of VOCs. Reductions of up to 45 percent may be required.

3. Travis Air Force Base -- Building 550

To be within compliance limits, the Bay Area Air Quality Management District (BAAQMD) requires that less than 13 kg of solvent be emitted from a paint application facility per day 14. Furthermore, less than 3.6 kg of solvent per hour should be emitted. According to the June 18 results of the ST-7 sampling interval, between 9:34 to 10:30, 1.82 kg of carbon were emitted from Stack 2. Furthermore, calculations indicate that emissions from Stacks 1 and 3 were nearly this high. The total carbon emission during this time interval was approximately 3.6 kg, which translates to approximately 5 kg of solvent. Test results for this facility accounted for 85 to 100 percent of the total VOC emissions expected. To be in compliance, VOC emissions may have to be reduced by as much as 30 percent.

4. Travis Air Force Base -- Building 1014

The ST-7 sampling results indicate that 4.5 kg of carbon were released in a 53-minute time interval. This translates to approximately 6.4 kg of solvent. Test results for this facility accounted for 23 to 100 percent of

the total VOC emissions expected. The BAAQMD standard was exceeded by approximately 70 percent, thus, a VOC emission reduction of at least 45 percent is required for compliance.

B. RECOMMENDATIONS

1. General

The installation of a recirculation booth, accompanied by a VOC control device, would be the most effective and maintenance-free method of eliminating VOC emissions from spray booth facilities. Such a system reduces the volume of air which requires processing to remove the solvents present in the flow. Simultaneously, the VOC concentration in the air passing through the VOC control device would be increased. This system, in addition to being cost effective, would allow for relatively maintenance-free operation. Recirculating the air in a paint spray booth can cause the VOC concentration in the booth to exceed the organic solvent TLV. For this reason, proper protective clothing and equipment should consist of a positive-pressure suit connected to a fresh air supply.

Another option would be to install charcoal filters in the exhaust ducts. Because these filters become saturated, care must be taken to change them when necessary. This results in increased maintenance costs.

The fastest and least expensive way to lower VOC emissions from all of the paint spray booths would be to adopt more efficient paint application devices such as electrostatic paint spray guns. This could decrease paint usage by as much as 50 percent, which would, in turn, decrease VOC emissions by as much as 50 percent.

A listing of possible modifications is given in Table 47. This table also includes the advantages and disadvantages associated with the modification, as well as relative costing estimates.

More than one of these modifications could be adopted. A carbon absorption system, used in conjunction with a more efficient paint application method, may require far less frequent carbon changeout.

2. McClellan Air Force Base

McClellan AFB personnel have expended considerable effort to reduce hazardous emissions from many of their painting facilities. Despite these efforts, further reductions are needed due to the use of coatings containing high VOC concentrations.

To decrease the quantity of air requiring processing with an add-on VOC control device, a recirculation system could be installed at the McClellan Building 655 paint spray booth for an approximate cost of \$60,000.

One safety measure which can be adopted immediately is that the fans (both the intake and the exhaust duct) be operated at all times during and

TABLE 47. POSSIBLE MODIFICATIONS WHICH MAY BE ADOPTED AT PAINT SPRAY FACILITIES AT MCCLELLAN AND TRAVIS AIR FORCE BASES

Modification	Relative cost	Approximate VOC emission reduction efficiency	Advantages	Disadvantages
Conventional air spray application	Low initial cost; low operating cost.	Negligible	Low cost, low maintenance requirements	Very low transfer efficiency
Air-assisted airless spray application	Low initial cost; low operating cost.	Slightly better than conventional spray	Low cost, low maintenance	Low transfer efficiency
Electrostatic spray application	Moderate initial costs; low-moderate operating costs.	Up to 50 percent	System can be implemented quickly; decrease of paint usage rate, thus more economical paint usage.	System may not be compatible with all the paints used at Travis and McClellan. More spray gun maintenance may be required. Transfer efficiency will vary as a function of target and environment.
Incineration	High initial cost; high operating cost.	Up to 100 percent	High removal efficiency possible	Would need several incinerators to handle volume flow
Carbon adsorption	Low-moderate initial cost; moderate-high operating costs.	Up to 95 percent	System is easy and rapidly deployed; high removal efficiency if system is properly maintained.	Frequent carbon filter changing may be required. Possibly high disposal costs.
Recirculation with add-on incineration device	Moderate-high initial costs; low operating costs.	Up to 100 percent	Relatively maintenance free; high removal efficiency.	Some problem with OSHA regulations may be encountered.
Recirculation with add-on carbon adsorption device	High initial cost; low or high operating costs	Up to 100 percent	High removal efficiency, hazard-free technology	Large quantities of water containing 10 percent solvent is generated -- could be costly to dispose of.

after a piece is painted in the booth. It was noticed that when the workmen had finished painting, they would leave the booth and turn off one or both sets of fans. While a painted piece is drying, considerable amounts of VOCs are emitted. By turning the fans off, the VOC concentration in the booth can become very high (see Table 9). This safety hazard can be eliminated by continuing fan operation in the booth while the painted surface dries. Another option is to install a delay mechanism into the fan "OFF" switch. This will continue fan operation for a specified period of time after the fans have been turned off.

Another safety recommendation is that fans should be operating and protective gloves worn while the workmen use large open containers of solvents such as MEK. Furthermore, open solvent containers should not be left in the room if the ventilation system is not operating.

Workmen would also frequently place large objects on the sump gratings which blocked the flow of air to the water sumps. While taking anemometer readings at the sump, sampling personnel noticed that the blockages did affect the surrounding flow. The grates should therefore be kept as clear as possible to allow unobstructed airflow.

3. Travis Air Force Base -- Building 550

One method of reducing VOC emissions from the Building 550 paint facility would be to adopt a more efficient paint application method. This could lower the VOC emissions by as much as 50 percent, and bring the spray booth into compliance. Another option would be to install flat charcoal filter cartridges behind the particulate filter sheets inside the spray booth. Because of the accessibility of this location, the filters could be easily changed, thus, minimizing maintenance time.

The particulate filters in the booth should be changed more frequently. At the current replacement rate, the particulate filter sheets become blocked (see Section II.B.2). This causes the fans in the exhaust ducts to draw air from the outside instead of from within the booth. The decrease in flow through the booth causes VOC concentrations to increase.

4. Travis Air Force Base -- Building 1014

This facility should be selected for a pilot study to determine the feasibility of installing a recirculation system to operate in conjunction with an add-on VOC emission control device. It is further recommended that two types of add-on devices be tested; a fume incinerator and a carbon adsorption steam regeneration unit. The 1014 spray booth is ideal for a pilot study, because of its operating schedule and because it has a fairly simple ventilation system. Since the booth is operated only a few months of the year for only 8 hours a day, paint booth operation would not be affected while the system is installed. A recirculation system could be installed at an approximate cost of \$33,000. Furthermore, it is possible to rent both an incinerator and a carbon adsorption unit for use in the pilot-scale test. This would allow for in-use evaluation and comparison between each device.

The VOC concentrations in the hangar surrounding the booth were high enough to cause eye irritation and headaches. The reason the concentrations were so high is that the exhaust outlet from the spray booth was flush with the hangar wall exterior. The exhausted air was directed downward by the wind through a ventilation opening in the hangar wall and back into the hangar area. It is recommended that at the very least, the exhaust duct be either directed upward or routed to the roof of the hangar.

Calculations of possible peak VOC concentrations revealed that the levels in the booth may, at times, exceed the TLV for specific solvents. For this reason, it is recommended that proper protective clothing be worn to prevent exposure to skin and face.

The particulate filters at the back of the booth clogged rapidly. This caused considerable leakage around the filter elements, which in turn allowed large quantities of particulate laden air to be exhausted (see Section II B-2). To avoid this problem, the filter elements should be changed more frequently, and cracks around the filter elements should be blocked.

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14. Regulation 8-4-303; Limitations on Noncomplying Solvents and Surface Coatings, Bay Area Air Quality Management District Rules and Regulations, March, 1982.

APPENDIX A

CALCULATIONS FOR DETERMINING THEORETICAL MASS OF CARBON IN STACK

The steps required to calculate the theoretical mass of carbon in the sampling stacks are outlined below.

1. The amount of paint used during the ST-7 sampling time interval was deduced from the paint usage log. The fraction which volatilized off was calculated by multiplying the paint used during the sampling interval by the percent volatile. This data is found in the results of the paint residue analysis (Tables 3 and 20):

$$\begin{array}{lcl} \text{Total Mass of Solvent} & = & \text{Mass of Paint} * \% \text{ Volatile} \\ \text{Released into Booth} & & \text{Used (kg)} \quad \text{by Mass} \end{array}$$

2. The mass of each volatile compound emitted was calculated by multiplying the percent by weight of each volatile component ('A') in the paint by the total amount of solvent emitted:

$$\begin{array}{lcl} \text{Mass of Component} & = & \text{Mass of Solvent} * \% \text{ by Weight of Component} \\ \text{'A' Emitted} & & \text{Emitted} \quad \text{'A' in the Paint} \end{array}$$

Frequently, paints and primers were mixed in prescribed ratios. In such cases, the contributions of each volatile component was quantified by considering the ratios in which the paints were mixed.

3. The percent by mass of carbon in each volatile component was calculated by using the molecular weights (MW) of both carbon and the compound of interest:

$$\begin{array}{l} \% \text{ by Weight} \\ \text{of Carbon in} \\ \text{Component 'A'} \end{array} = \frac{1}{\text{MW of Component 'A'}} * \frac{\text{Moles of Carbon}}{\text{Mole of Compound}} * \text{MW of Carbon}$$

There is some uncertainty in the results from this step because the GC/MS data reported several VOCs in the paint as unknowns, thus the percent carbon in these compound could not be included.

4. The total mass of carbon volatilized off in the booth is calculated by summing the carbon contributions from each component:

$$\begin{array}{lcl} \text{Total Mass} & & \text{Total Mass} \\ \text{of Carbon} & = & \text{Emitted of} \\ \text{Emitted} & & \text{Component i} \end{array} * \begin{array}{l} \% \text{ by Weight} \\ \text{of Carbon in} \\ \text{Component i} \end{array}$$

5. The amount of carbon (by weight) to be found in each stack is determined by the flow rates measured in the stacks. The percent of the total flow exhausted through a particular stack determines what percentage of the total mass of carbon is associated with that stack. For example, at Building 550 at Travis Air Force Base, stacks 1 and 2 are considerably larger than Stacks 3 and 4. The painting that was done in Quadrant 1 was associated only with Stacks 1 and 2, and the amount of carbon exhausted by each of these stacks was determined by the percentage flow through each stack. It should be noted that the mass of carbon estimated by this method will be lower than the actual carbon concentration due to uncertainties in the volume flow measurements.

APPENDIX B
METRIC CONVERSION TABLE

Metric To English

Length:

$$1\text{cm} = 0.394\text{ in}$$

$$1\text{m} = 3.28\text{ ft}$$

Volume:

$$1\text{ L} = 0.0353\text{ ft}^3$$

$$= 0.264\text{ gal}$$

$$1\text{ m}^3 = 35.31\text{ ft}^3$$

$$= 264.2\text{ gal}$$

Mass:

$$1\text{ Kg} = 2.2\text{ lb}$$

Temperature:

$$^{\circ}\text{C} = 5/9 (^{\circ}\text{F}-32)$$

English to Metric

Length:

$$1\text{ in} = 2.54\text{ cm}$$

$$1\text{ ft} = 0.3048\text{ m}$$

Volume:

$$1\text{ ft}^3 = 28.3\text{ L}$$

$$= 0.0283\text{ m}^3$$

$$1\text{ gal} = 3.79\text{ L}$$

$$= 0.00379\text{ m}^3$$

Mass:

$$1\text{ lb} = 0.454\text{ Kg}$$

Temperature:

$$^{\circ}\text{F} = 9/5 ^{\circ}\text{C}+32$$

APPENDIX C

DESCRIPTION OF SAMPLING AND MEASURING PROCEDURES

A. VOLUME FLOW MEASUREMENTS

Two volume flow measurement procedures were used in this study: EPA Method 2 and anemometry data. EPA Method 2 was used to measure volume flow through ducts, while the anemometer was used to measure flow at grates, sumps, and filter faces.

EPA Method 2 uses a pitot tube to measure pressure differentials in a duct at specified traverse points. The pitot readings are corrected to standard conditions and summed to yield the flow through the duct. The pressure differential data must be taken at a site located at least eight duct diameters downstream and two diameters upstream from any flow disturbance (C-1).

For anemometer flow measurements done in this study, the surface to be measured was subdivided into sections. Data were taken over each section approximately 3 inches from the surface of interest. The anemometer gives a measurement of the flow velocity over a section; when multiplied by the section area, the volume flow is calculated. These data are also corrected to standard conditions.

B. MEASUREMENT OF ORGANIC CONSTITUENTS

1. Continuous Monitors

Two continuous monitoring procedures were used to determine the concentration of organics in the flow: EPA Method 25A and Bay Area Air Quality Management District (BAAQMD) Method ST-7.

Both EPA Method 25A and BAAQMD Method ST-7 are gas analysis procedures which determine the total oxidizable carbon (TOC) concentration in a sample stream. TOC is comprised of the organic carbon and carbon monoxide present in the sample. For the tests discussed in this report, the contribution of carbon monoxide to the TOC concentration was considered negligible (CO concentrations in air is generally a few parts per million), thus the measured TOC was considered to be solely from an organic source.

The BAAQMD ST-7 procedure requires a gas sample to be passed through a combustion tube where all organic carbon atoms are oxidized to CO_2 (C-2). From the combustion tube, the sample is passed through a nondispersive infrared analyzer (NDIR) which continuously monitors the CO_2 concentration in the gas stream. Periodically, the combustion tube is bypassed, and the sample gas is passed directly through the NDIR. This is done to measure the sample background concentration of CO_2 . The difference between the CO_2

concentrations in these streams is the TOC concentration in the sample. The ST-7 results are accurate because the NDIR analyzer is calibrated with CO₂, which is also the gas being measured.

The EPA Method 25A utilizes a flame ionization detector (FID) to analyze the TOC concentration in the sample gas (C-3). The FID is sensitive to the total hydrocarbon concentration in the sample stream, and it does not distinguish between organic species. Thus, in order to correctly assess the VOC concentration in the sample, the components and the relative concentrations of the components in the sample stream must be known.

C. VOLATILE ORGANIC CONSTITUENT CHARACTERIZATION

The volatile constituents in the stack gas streams were qualified by using the National Institute of Safety and Health (NIOSH) sampling Method 1300.

In this procedure, a small volume of stack gas is drawn through a NIOSH tube containing activated charcoal. The flow rates used are between 0.01 and 0.24 liters per minute, and the total volume sampled is generally less than 25 liters. The volatile organics are adsorbed onto the surface of the charcoal, and are later removed by chemical extraction.

D. SEMIVOLATILE ORGANIC CONSTITUENTS

Semivolatile compound concentrations were measured in the stack gas using the EPA Modified Method 5 (MM5) sampling and analyses protocol. (C-2) Figure C-1 illustrates the MM5 sampling system used in this program. 65g of XAD-2 organic sorbent was packed in a glass module in the field. Both the condenser and the XAD-2 module were water-jacketed to maintain the flue gas temperature entering the XAD-2 sorbent at approximately 60°F. The first modified impinger trapped organic condensate. The remaining distilled H₂O and silica gel impingers were used primarily to trap the remaining moisture in the flue gas. The convection oven was equipped with a filter.

The sample flowrate was approximately 280 mL/second (0.6 dscf), and the sample volume was generally greater than 0.867 dscm (30 dscf) for a 1-hour sampling period.

E. PARTICULATE MEASUREMENT

Two procedures were used to quantify particulate emissions. EPA MM5 and NIOSH nuisance dust test Method 500. The MM5 test was used to determine stack concentrations of particulate, and the NIOSH 500 procedure determined particulate concentrations both in the spray booth and in the stack.

The MM5 apparatus (described in a previous section) was equipped with a five mesh particulate filter. The particulate collected on the filter as well as that deposited in the probe was weighed to determine total particulate emissions from the stack.

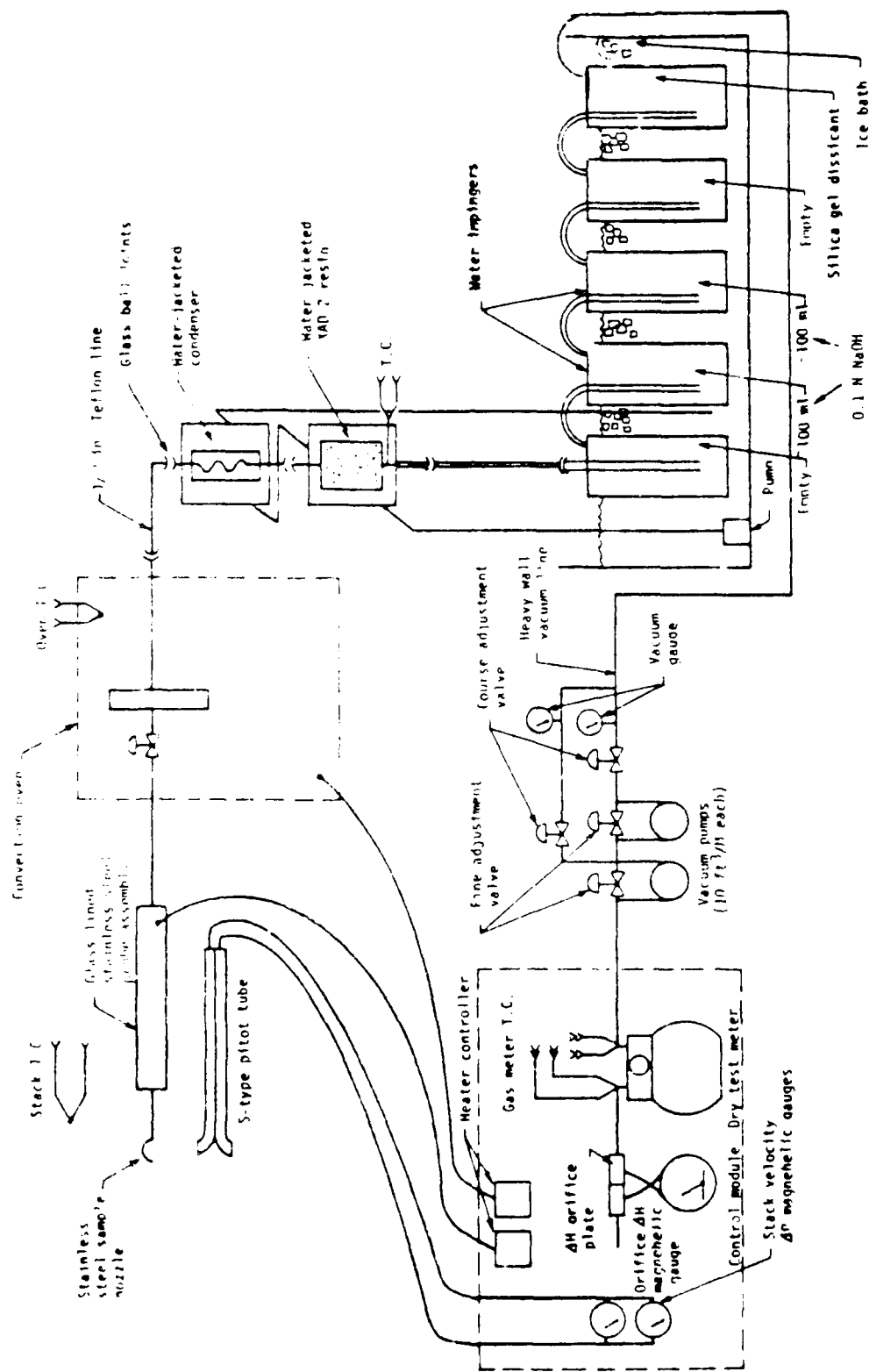


Figure C-1. EPA Modified Method 5 Train.

The NIOSH 500 procedure involves drawing a large volume of sample air through a fine mesh filter. The flowrate generally used is approximately 1.5 to 2 liters per minute. The total sample volume drawn is usually 15 to 133 liters. The filters are removed from the sample cartridges and then weighed to determine the total quantity of particulate collected.

REFERENCES FOR APPENDIX C

- C-1. EPA Method 2: Determination of Stack Gas Velocity and Volumetric Flowrate (Type S Pitot Tube), Environmental Protection Agency Sampling Methods, 40 CFR, part 60, Appendix A.
- C-2. U.S. EPA EMSL, "Modified Method 5 Train and Source Assessment Sampling System Operator's Manual," EPA-600/8-85-003, February 1985.

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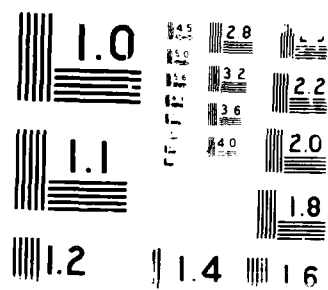
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APPENDIX D

QUALITY ASSURANCE PROCEDURES

Appendix D describes the quality control measures which were implemented for this test series. The accuracy, precision, and completeness of all data obtained are assessed. Project quality assurance objectives for these three parameters are given in Table D-1. The following measures were put into effect to ensure these objectives were met.

- Blind trip blanks were submitted for analysis with all EPA MM5 samples and most NIOSH 1300 samples
- Duplicate samples were submitted for analysis with all EPA Method 624 (Method 624) water samples
- All Method 624 and Method 625 samples were spiked with surrogate compounds, and the percent recovery of these compounds is reported
- Method 624 and Method 625 analyses were performed on laboratory storage and/or method blanks

A complete set of samples was acquired with every sampling effort. Test matrices for each site and complete sampling protocols were developed prior to sampling and testing. All sources in the test matrices were sampled, and only a few trip blanks were missed. Duplicates were submitted whenever possible; due to the dynamic nature of the sampling procedure, duplicates were not usually obtainable. Samples were analyzed as soon as possible by the Acurex Chemistry Laboratory.

The accuracy and completeness of each data set were determined based on the quality control measures cited above and are presented in the following paragraphs.

E. METHOD 624 ANALYSES ON WATER SAMPLES

To ensure accurate results, a three-point calibration curve was prepared for the relevant compounds. A daily response factor check was conducted to test instrument calibration. If a deviation greater than 20 percent occurred, the system was either recalibrated or fresh standards were prepared to verify calibration.

The accuracies of the Method 624 analyses performed on water samples were assessed by determining the surrogate recoveries from each of the spiked samples. The samples were spiked with three surrogate compounds: 1,2-dichloroethane, toluene, and p-bromofluorobenzene. The percent recoveries of surrogate compounds ranged from 45 to 225 percent, as shown in Table D-2. The accuracy DQO for this measurement was 50 to 140 percent and

TABLE D-1. PRECISION, ACCURACY, AND COMPLETENESS OBJECTIVES

Measurement parameter	Measurement/analytical method	Reference	Precision relative percent difference	Accuracy (percent)	Completeness
Volume flow	Hot wire Anemometer ACGIH method	ACGIH ^a	--	--	90
Duct flow	EPA Method 2	40 CFR 60 Appendix A	--	--	90
Volatile organics in air	NIOSH 1300 carbon absorption extraction, GC/FID	bdHHS (NIOSH) 84-100	25	70 to 120	90
Semivolatile organics in sump water	EPA Method 625 MeCl ₂ extraction GC/MS	EPA-600/4-82-057 ^c	30	50 to 140	90
Volatiles organics in sump water	EPA Method 624 Capillary GC/MS Purge and trap GC/MS	EPA-600/4-82-057 ^c	30	50 to 140	90
Semivolatile organics in air	EPA MMt MeCl ₂ extraction of XAD, GC/MS	SW-846 2nd Ed. Revised ^d (1984)	30	50 to 140	90
TUHC	Continuous FID	40 CFR 60 Appendix A	--	±2%	90

^aIndustrial Ventilation -- A Manual of Recommended Practices, 14th Ed., American Council of Governmental Industrial Hygienists, Committee on Industrial Ventilation.

^bNIOSH Manual of Analytical Methods, Department of Health Services M.

^cMethods for Organic Chemical Analysis of Municipal and Industrial Waste Waters, U.S. EPA Environmental Monitoring and Support Laboratory, July 1982.

^dProposed Sampling and Analytical Methodologies for Addition to SW-846, Test Methods for Evaluating Solid Waste: Physical Chemical Methods (2nd Ed.), 1984.

TABLE D-2. VOLATILE ORGANIC ANALYSIS: WATER

Percent recoveries										
Surrogates	905368	905369	905370	905372	905374	905402	905404	905412	905413	
	Make up	Sump 10	Sump 9	Sump 11	Sump 12	Sump 9	Sump 10	Sump 11	Sump 12	
1,2-Dichloroethane	89	94	103	94	94	172	210	131	225	
Toluene	89	95	99	98	93	68	45	138	138	
p-Bromofluorobenzene	85	84	51	85	79	58	54	173	173	

the completeness DQO was 90 percent. Of the 27 compounds that were analyzed, 22 percent fell outside the DQO limits. The completeness for this measurement is therefore 78 percent, which is below the completeness DQO.

Storage and trip blanks were analyzed to determine the degree to which contamination occurred in the samples during transport, storage, and analysis. The results indicate that no contamination occurred.

F. METHOD 625 ANALYSES

To ensure accurate results, a three-point calibration curve was prepared for the relevant compounds. A daily response factor check was conducted to test instrument calibration. If a deviation greater than 20 percent occurred, the system was either recalibrated or fresh standards were prepared to verify calibration.

The accuracies of the Method 625 analyses performed on water samples were assessed by determining the surrogate recoveries from each of the spiked samples. The samples were spiked with six surrogate compounds: 2-fluorophenol, phenol, nitrobenzene, 2-fluorobiphenyl, 2,4,6-tribromophenol, and terphenyl. The percent recoveries of surrogate compounds ranged from 6 to 137 percent, as shown in Table D-3. The accuracy DQO for this measurement was 50 to 140 percent and the completeness DQO was 90 percent. Of the 54 compounds that were analyzed, 4 percent fell outside the DQO limits. The completeness for this measurement is, therefore, 96 percent, which is within the completeness DQO.

A storage blank was also analyzed to determine the degree to which contamination occurred in the samples during storage and analysis. The results indicate that no contamination occurred.

G. NIOSH 1300 ANALYSES

To ensure accurate results, a three-point calibration curve was prepared for the relevant compounds. A daily response factor check was conducted to test instrument calibration. If a deviation greater than 20 percent occurred, the system was either recalibrated or fresh standards were prepared to verify calibration.

The desorption efficiencies of compounds detected in the samples were determined by spiking clean NIOSH tubes with the compounds of interest. Three sets of tubes were submitted for analysis to the Acurex Chemistry Laboratory, thus three clean tubes were spiked with the compounds detected in the samples. The results of the desorption efficiency analyses are presented in Table D-4. The accuracy DQO for this measurement was desorption efficiencies in the range of 70 to 120 percent; as shown in Table D-4, the actual range was from 78 to 109 percent. All desorption efficiencies fell within the DQO limits, thus, the completeness of this measurement is 100 percent.

TABLE D-3. SEMIVOLATILE ORGANIC ANALYSIS: WATER

		Percent recoveries									
Surrogates	905368 Make up	905369 Sump 10	905370 Sump 9	905372 Sump 11	905374 Sump 12	905397 Sump 9	905403 Sump 10	905407 Sump 12	905410 Sump 11		
2-Fluorophenol	47	54	53	55	53	54	72	51	69		
Phenol	6	67	60	63	61	52	79	77	73		
Nitrobenzene	79	74	66	82	80	64	76	82	87		
2-Fluorobiphenyl	70	70	54	77	80	58	70	75	87		
2,4,6-Tribromophenol	82	76	73	79	74	66	95	101	64		
p-Terpenyl	95	79	79	96	83	115	96	99	137		

TABLE D-4. VOLATILE ORGANIC ANALYSIS: NIOSH 1300
CHARCOAL TUBES

Surrogates	Desorption efficiencies of the test compounds (%)		
	Set 1 ^a	Set 2 ^b	Set 3 ^b
2-Butanone	103		
2-Propanol	85	90	90
4-Methyl-2-pentanone	103	98	98
Toluene	101	96	96
Butyl acetate	106	109	109
5-Methyl-2-hexanone	103		
2-Butoxy ethanol	78		
Propyl acetate		105	105
o-Xylene		98	98
m-Xylene		103	103
p-Xylene		98	98

^aMinimum detection limit:
0.004 mg/tube front half
0.001 mg/tube back half

^bMinimum detection limit: 0.0005 mg/tube

In some instances, trip blanks were submitted for analysis to determine the degree of contamination which may have occurred during sample transport, storage, and analysis. In each case, no contaminants were detected, thus no data correction was required.

It was not possible to collect duplicates of the NIOSH 1300 samples due to the variable nature of the sampling process. For this reason, the precision of the data generated could not be determined.

H. MME ANALYSES

The accuracies of the MM5 analyses were assessed by determining the surrogate recoveries from each of the spiked samples. The samples were spiked with four to six of the following surrogate compounds: 2-fluorophenol, phenol, nitrobenzene, 2-fluorobiphenyl, 2,4,6-tribromophenol, and terphenyl. The percent recovery of surrogate compounds ranged from 0 to 136 percent, as shown in Table D-5. The accuracy DQO for this measurement was 50 to 140 percent and the completeness DQ was 90 percent. Of the 47 surrogates that were analyzed, 13 percent fell outside the DQ limits. The completeness for this measurement is therefore 87 percent, which is slightly below the completeness DQO.

Trip blanks were also analyzed to determine the level of contamination which may have occurred during sample transport, storage, and analysis. It was found that no contamination of the samples occurred.

It was not possible to collect duplicates of the MM5 samples due to the variable nature of the sampling process. For this reason, the precision of the data generated could not be determined.

TABLE D-5. SEMIVOLATILE ORGANIC ANALYSIS: M15 SAMPLES

Surrogates	Percent recoveries									
	June 3	June 3	June 16	June 17	June 17	June 18	June 18	June 18	June 29	June 30
								blank		
2-Fluorophenol	68	2	NS	NS	NS	NS	NS	NS	NS	NS
Phenol	13	65	NS	NS	NS	NS	NS	NS	54	68
Nitrobenzene	41	45	72	82	64	78	72	72	93	74
2-Fluorobiphenyl	119	107	77	84	67	80	73	73	97	74
2,4,6-Tribromophenol	80	84	NS	NS	NS	NS	NS	NS	NS	NS
p-Terpenyl	106	136	104	87	91	81	83	83	78	75

NS -- Not spiked.

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